



US009192287B2

(12) **United States Patent**  
**Saadat et al.**

(10) **Patent No.:** **US 9,192,287 B2**  
(45) **Date of Patent:** **Nov. 24, 2015**

(54) **TISSUE VISUALIZATION DEVICE AND METHOD VARIATIONS**

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/526,254**

(22) Filed: **Jun. 18, 2012**

(65) **Prior Publication Data**

US 2013/0023731 A1 Jan. 24, 2013

**Related U.S. Application Data**

(63) Continuation-in-part of application No. 11/848,202, filed on Aug. 30, 2007, now Pat. No. 8,221,310, which is a continuation-in-part of application No. 11/259,498, filed on Oct. 25, 2005, now Pat. No. 7,860,555.

(60) Provisional application No. 60/824,418, filed on Sep. 1, 2006, provisional application No. 60/824,423, filed on Sep. 1, 2006.

(51) **Int. Cl.**

**A61B 1/00** (2006.01)  
**A61B 1/005** (2006.01)  
**A61B 1/015** (2006.01)  
**A61B 1/018** (2006.01)  
**A61B 1/04** (2006.01)  
**A61B 5/02** (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ..... **A61B 1/005** (2013.01); **A61B 1/0008** (2013.01); **A61B 1/00082** (2013.01); **A61B 1/00085** (2013.01); **A61B 1/00089** (2013.01); **A61B 1/00091** (2013.01); **A61B 1/00177** (2013.01); **A61B 1/015** (2013.01); **A61B 1/018**

(2013.01); **A61B 1/04** (2013.01); **A61B 5/02007** (2013.01); **A61B 5/6882** (2013.01); **A61B 17/0057** (2013.01); **A61B 17/00234** (2013.01); **A61B 17/0401** (2013.01); **A61B 8/12** (2013.01); **A61B 17/0469** (2013.01); **A61B 17/0487** (2013.01); **A61B 17/22012** (2013.01); **A61B 18/24** (2013.01); **A61B 2017/048** (2013.01); **A61B 2017/0496** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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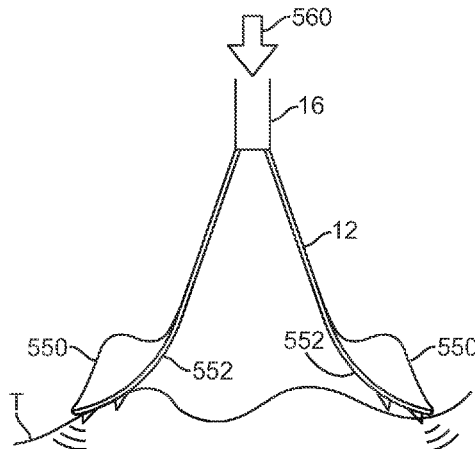
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**ABSTRACT**

Tissue visualization devices and variations thereof are described herein where such devices may utilize a variety of methods for facilitating clearing of the device of opaque bodily fluids and sealing between the device and the underlying tissue surface. Additionally, methods and devices for enhancing navigation of the device through a patient body are also described.

**20 Claims, 55 Drawing Sheets**



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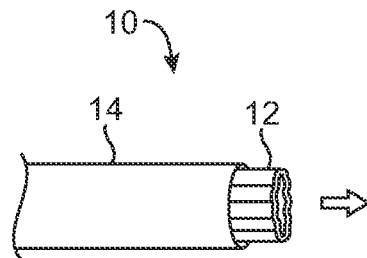


FIG. 1A

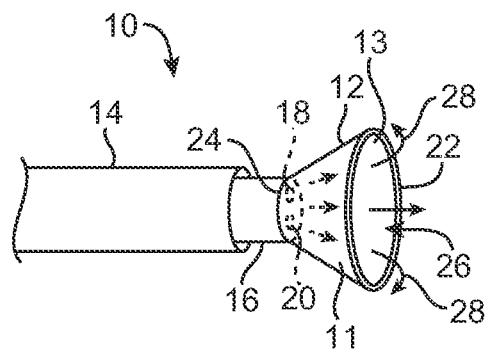


FIG. 1B

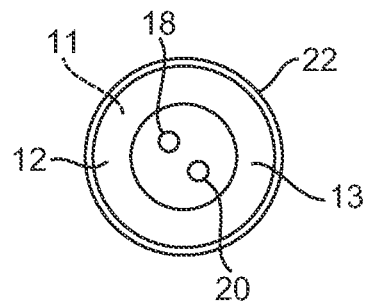


FIG. 1C



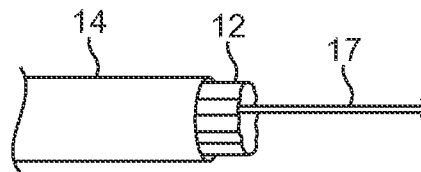


FIG. 1D

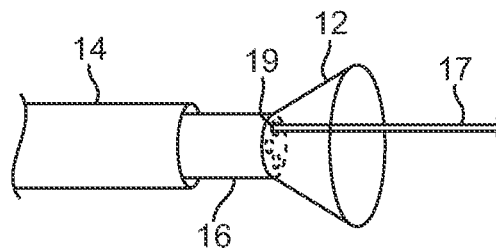


FIG. 1E

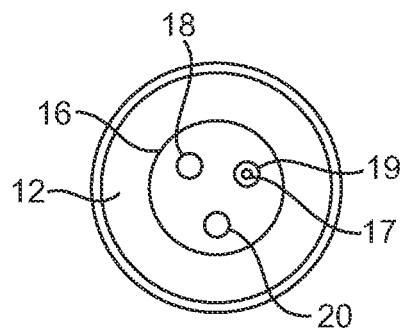


FIG. 1F

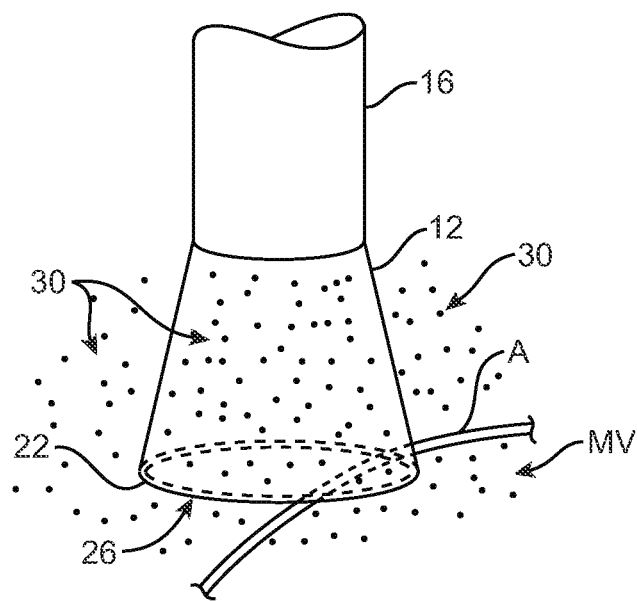


FIG. 2A

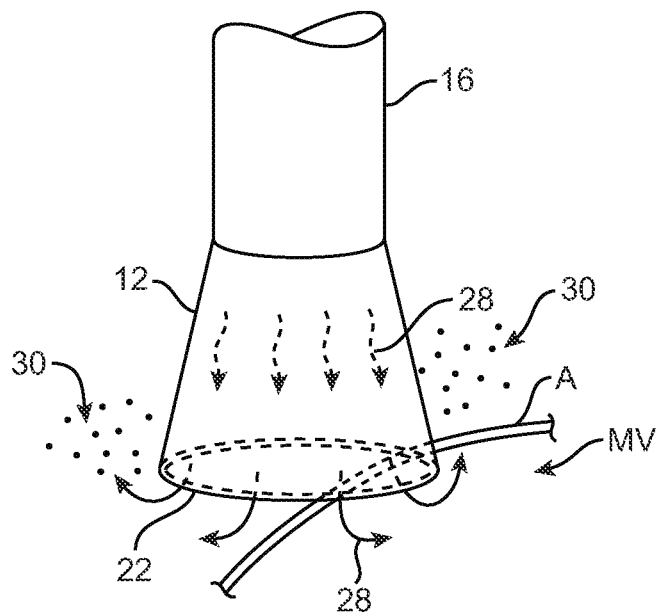


FIG. 2B

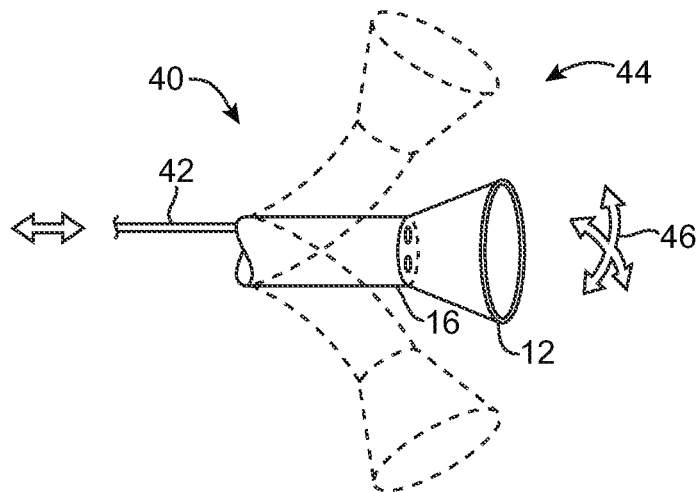


FIG. 3A

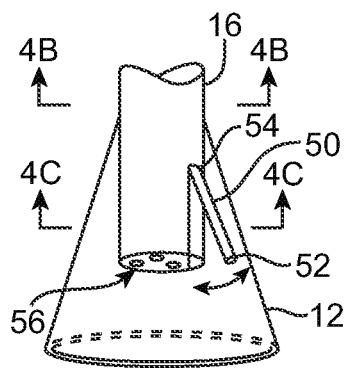


FIG. 4A

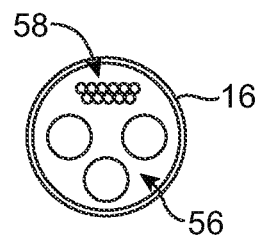


FIG. 4B

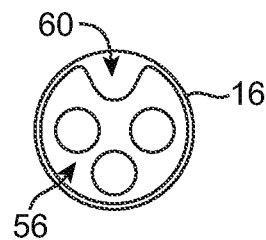


FIG. 4C

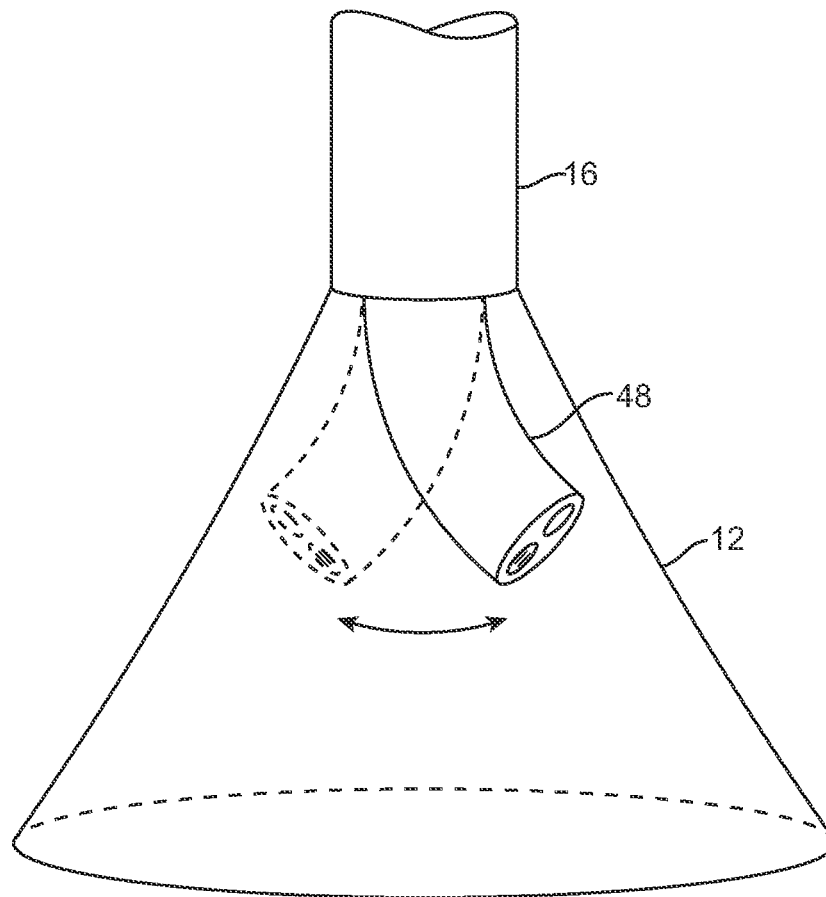


FIG. 3B

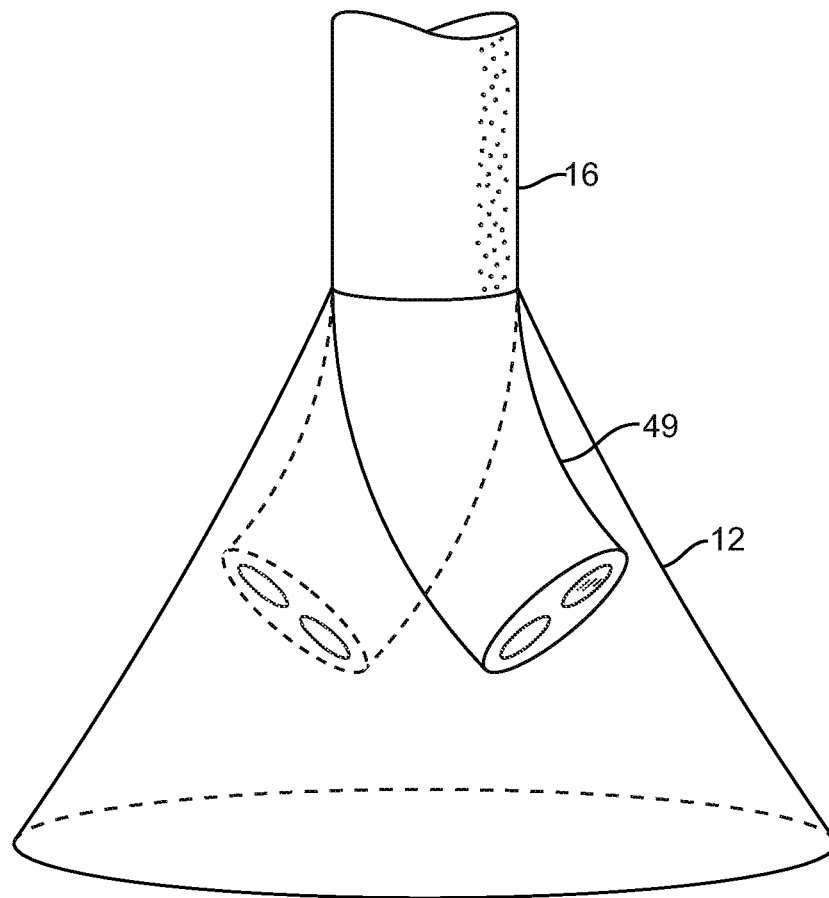


FIG. 3C

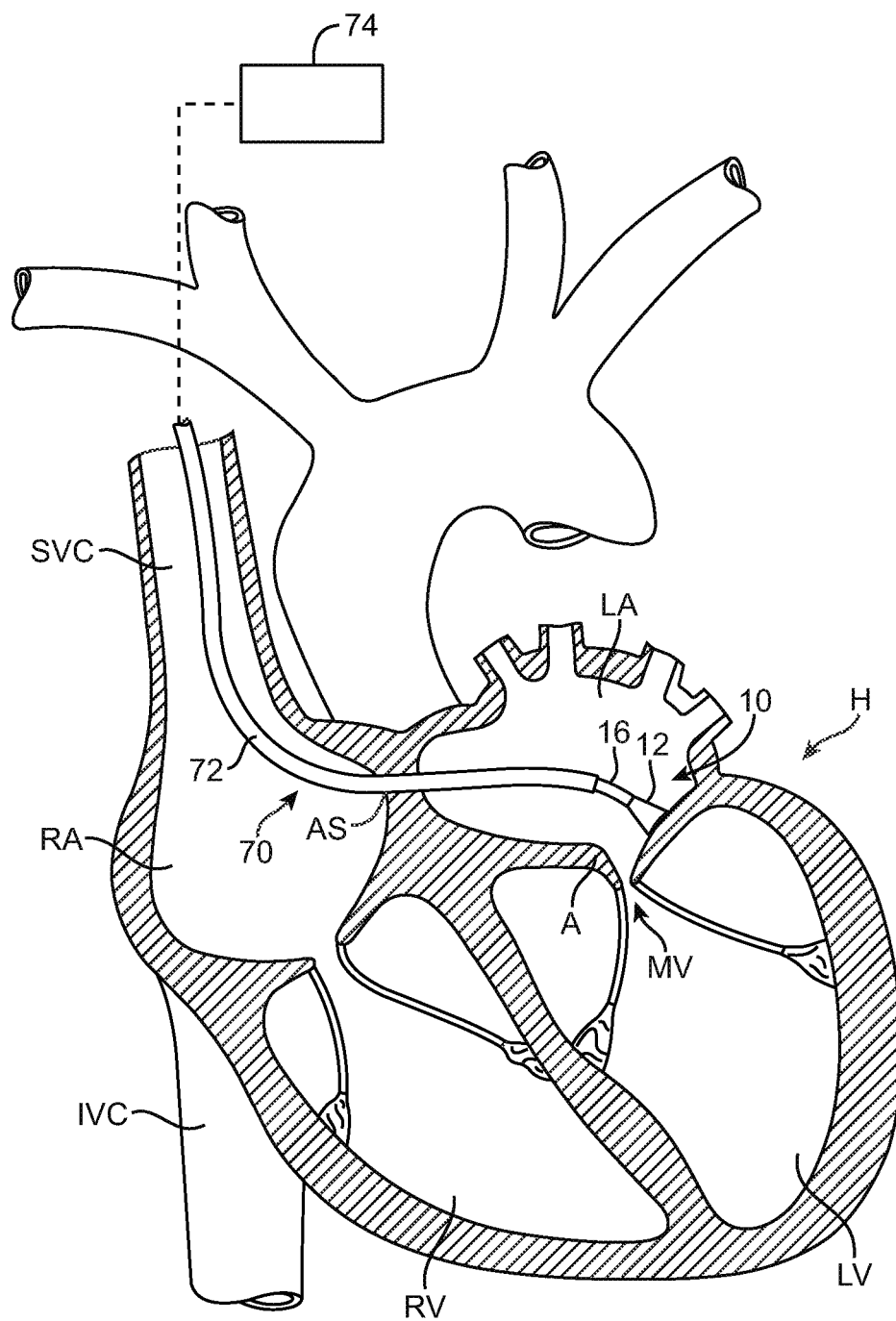


FIG. 5

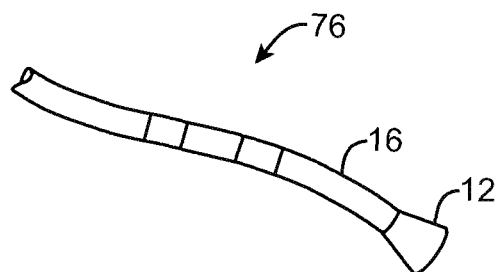


FIG. 6A

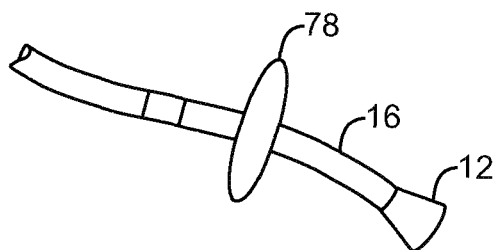


FIG. 6B

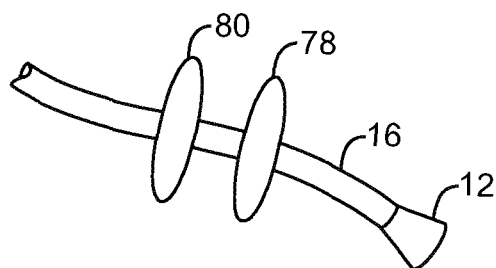


FIG. 6C

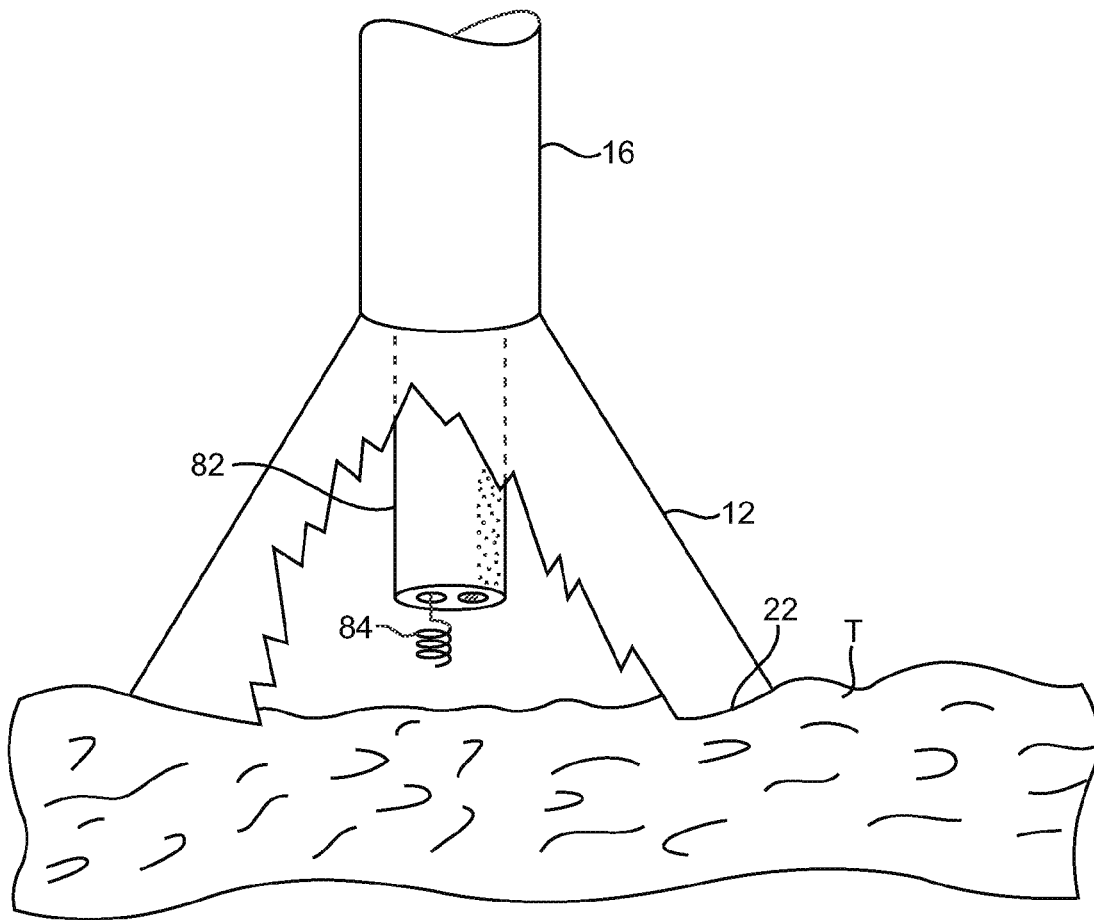


FIG. 7A



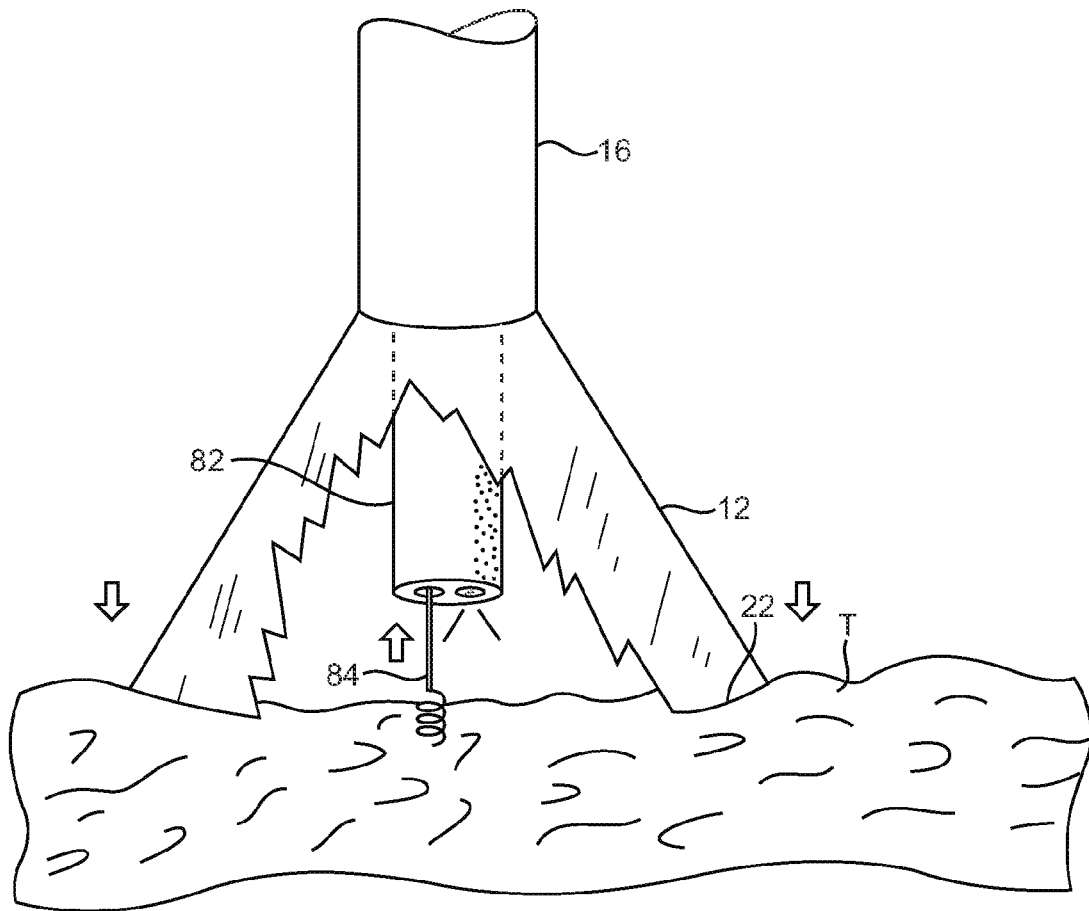


FIG. 7B

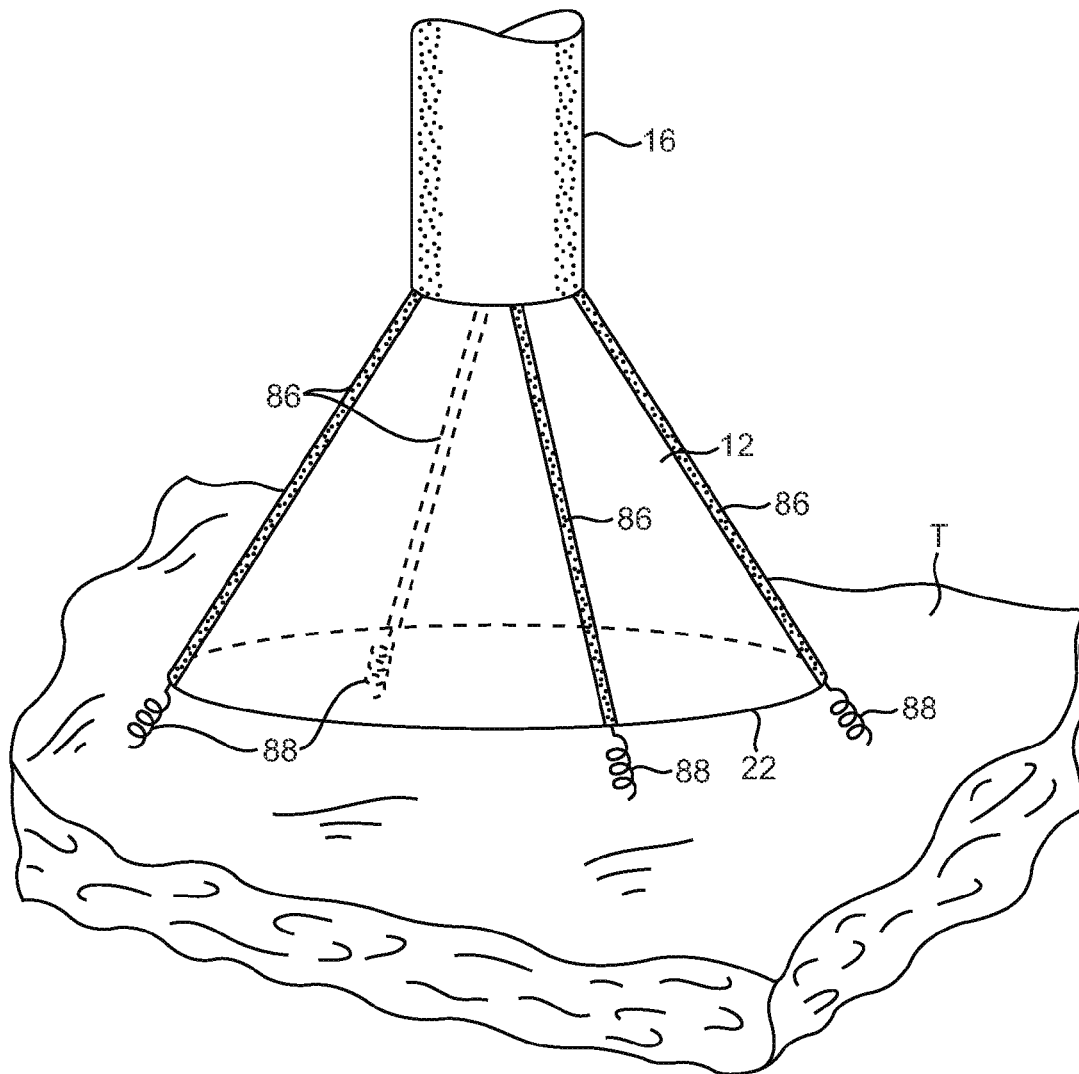


FIG. 7C

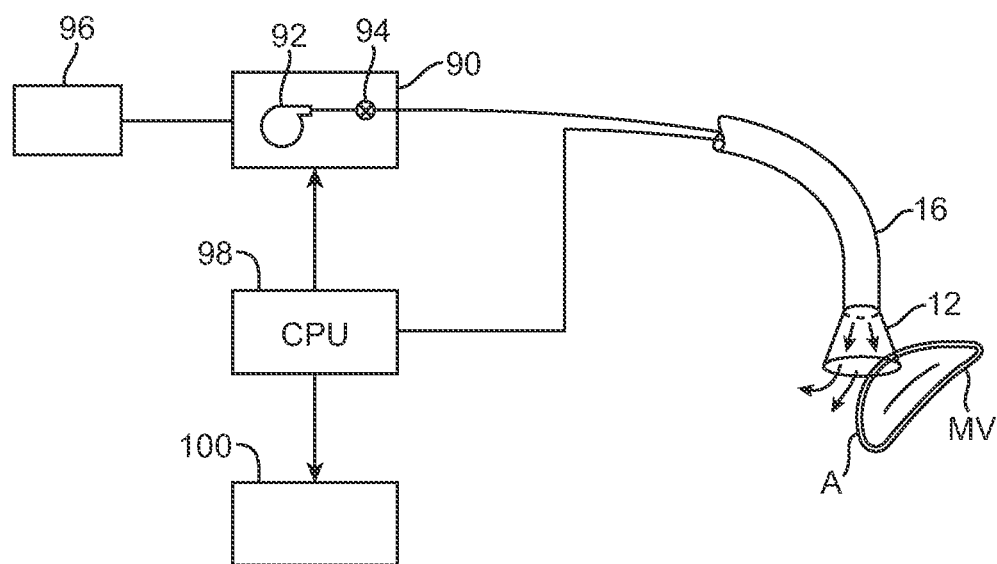


FIG. 8A

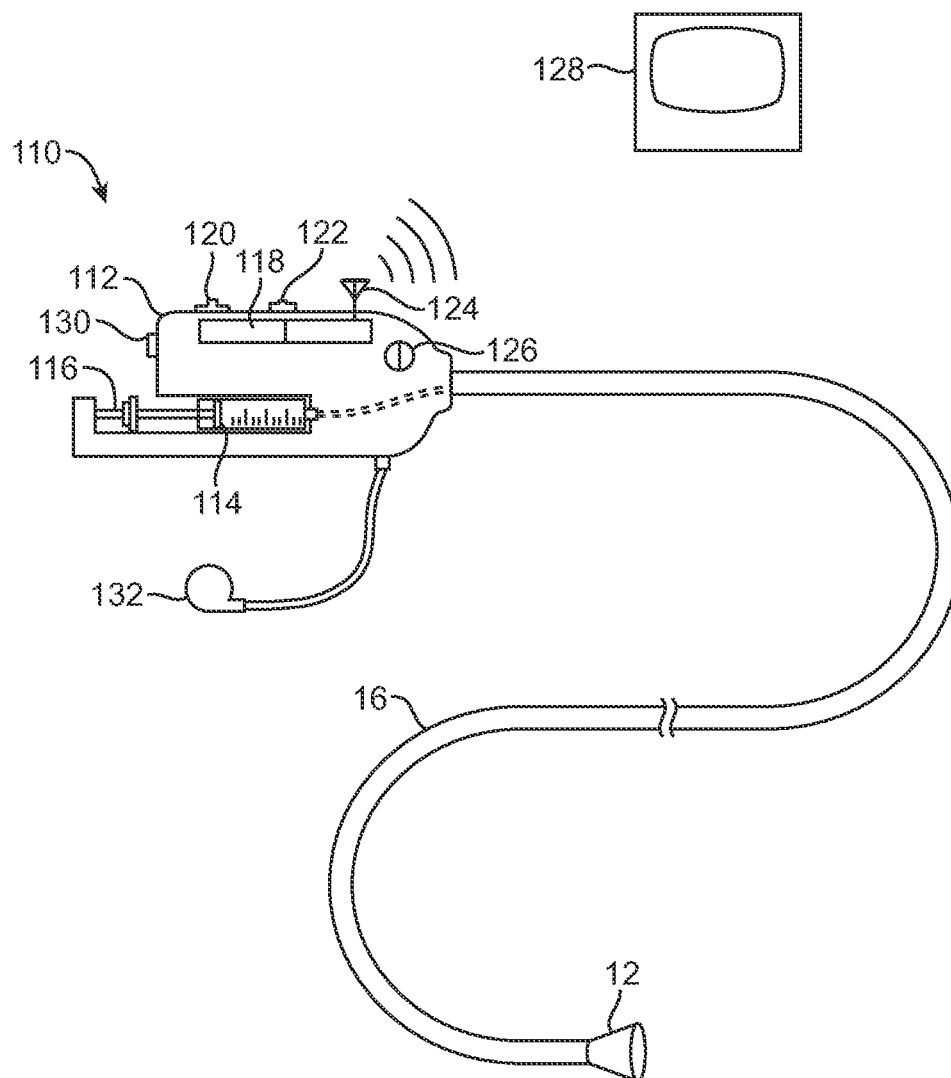
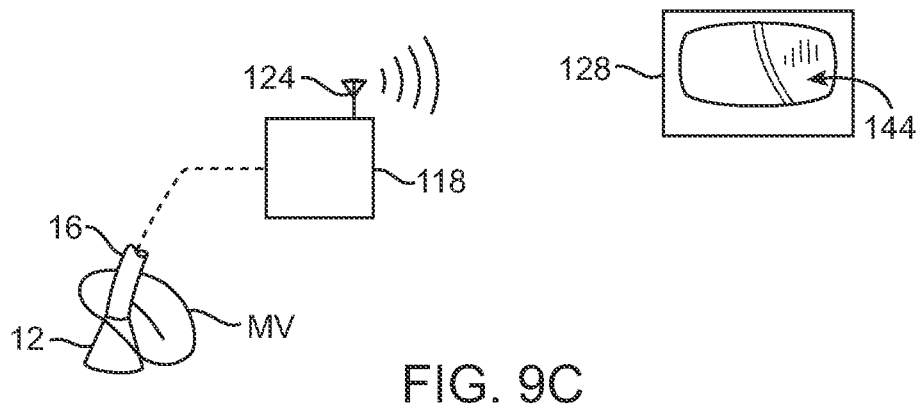
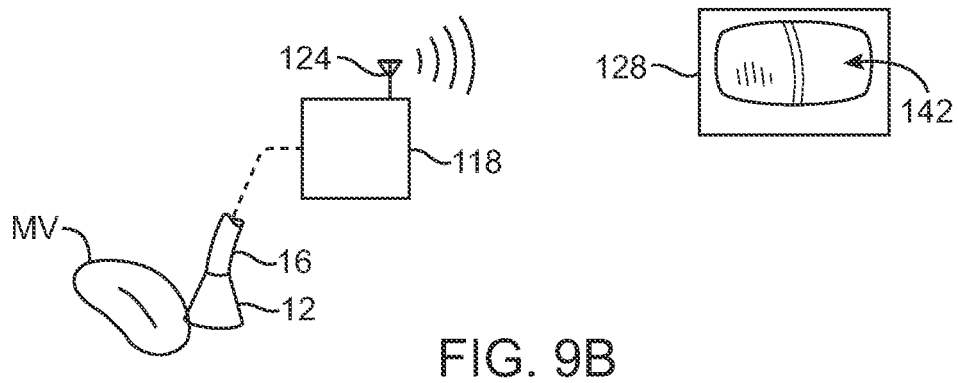
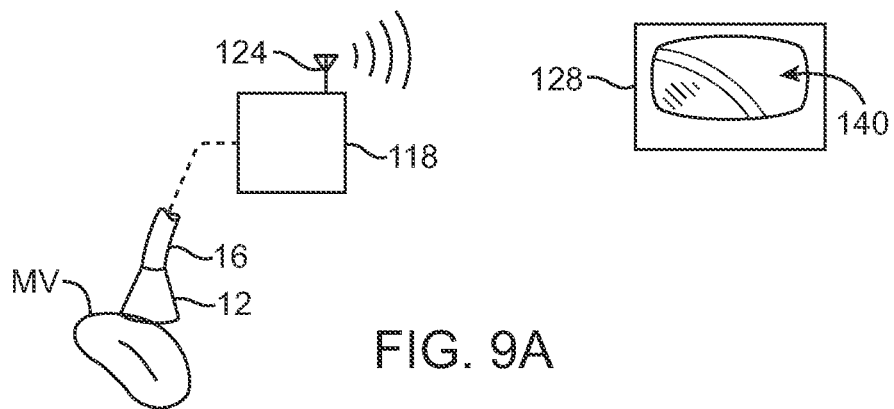


FIG. 8B



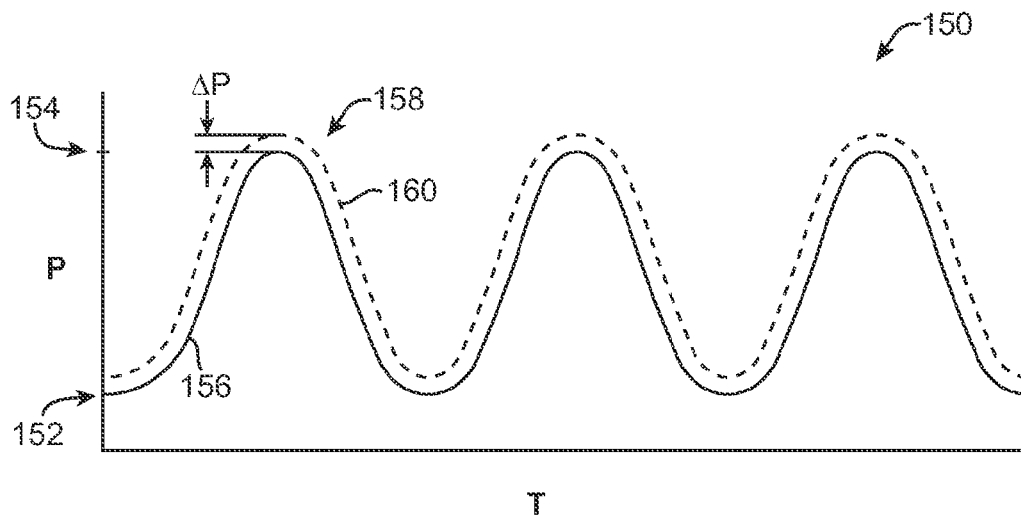


FIG. 10A

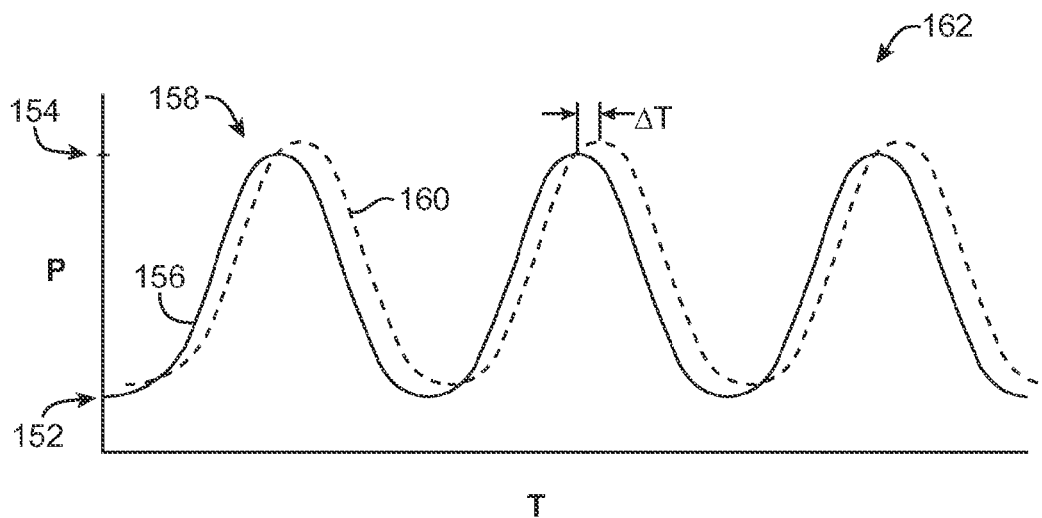


FIG. 10B

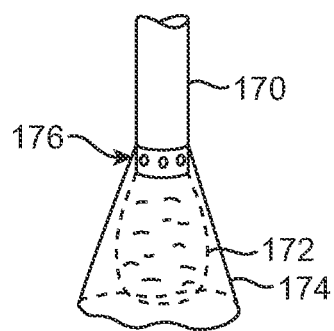


FIG. 11A

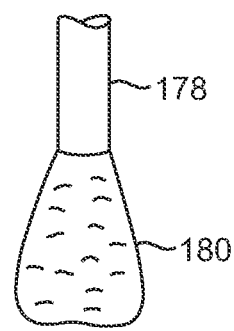


FIG. 11B

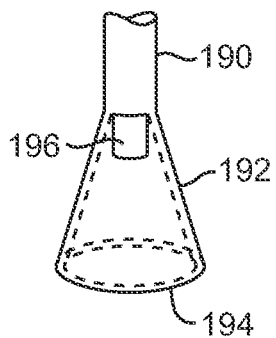


FIG. 13A

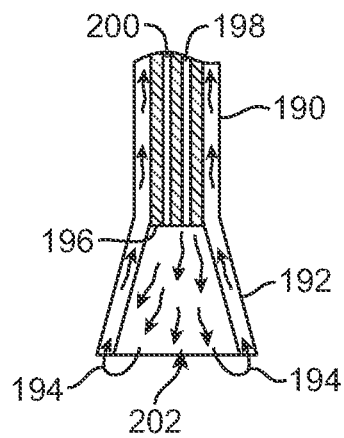


FIG. 13B

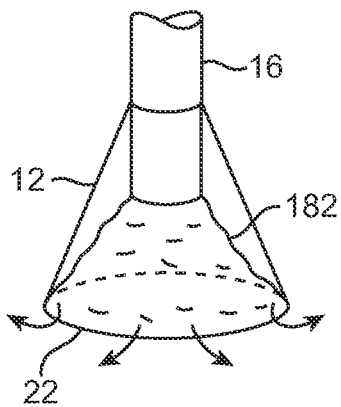


FIG. 12A

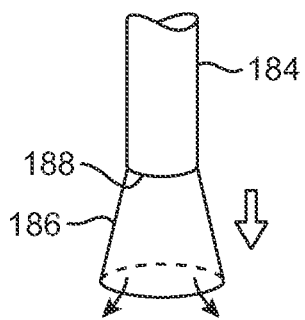


FIG. 12B

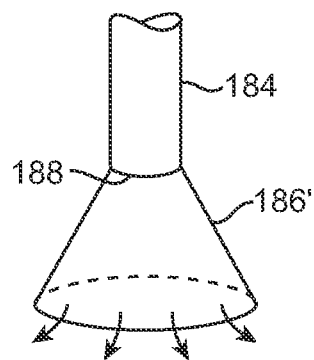


FIG. 12C



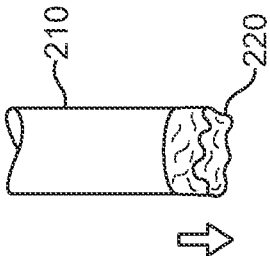


FIG. 14D

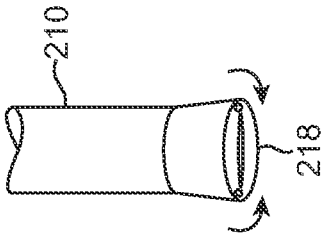


FIG. 14C

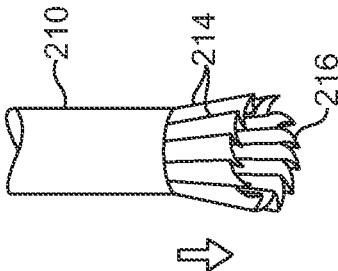


FIG. 14B

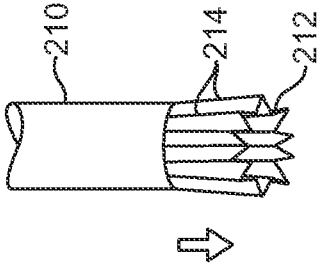


FIG. 14A

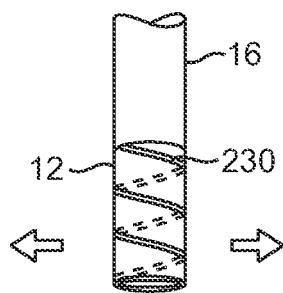


FIG. 15A

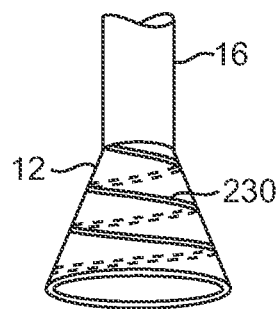


FIG. 15B

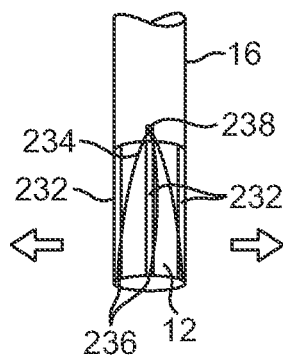


FIG. 16A

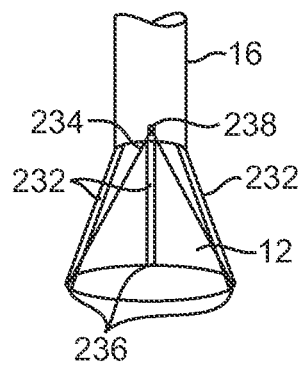


FIG. 16B

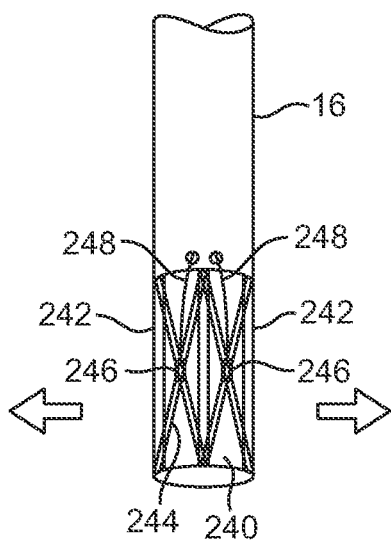


FIG. 17A

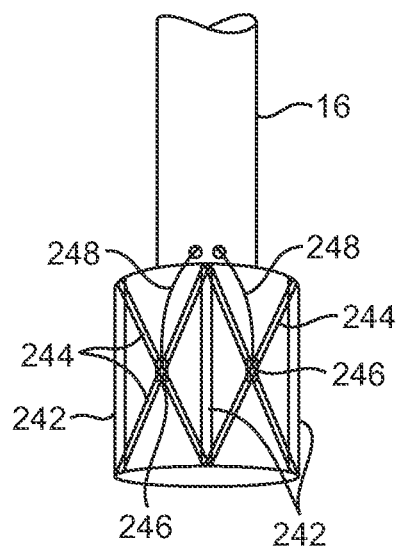


FIG. 17B

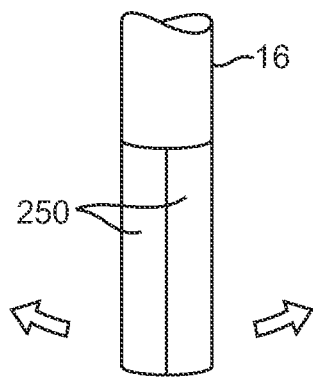


FIG. 18A

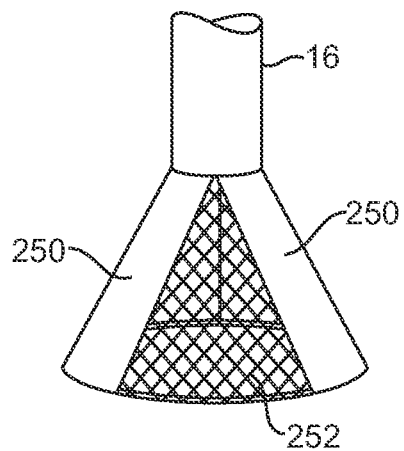


FIG. 18B

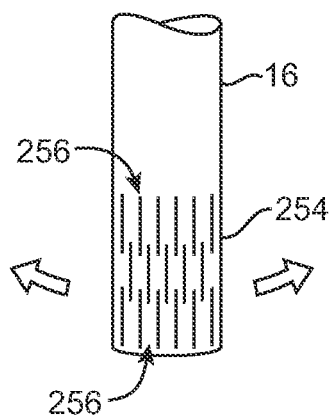


FIG. 19A

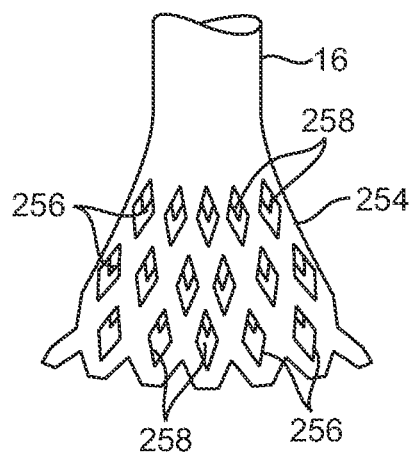


FIG. 19B

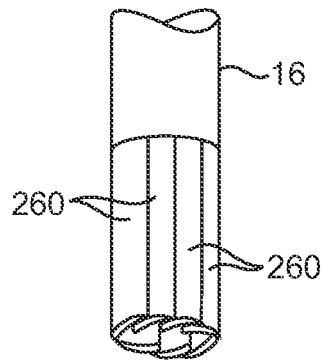


FIG. 20A

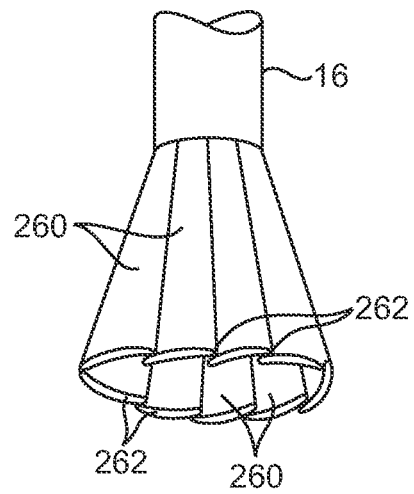


FIG. 20B

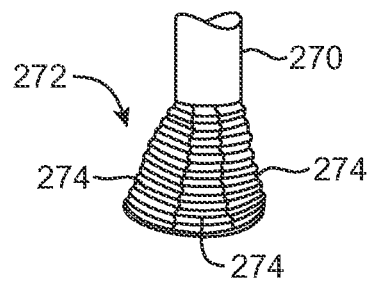


FIG. 21A

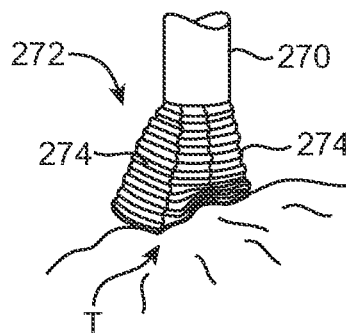


FIG. 21B

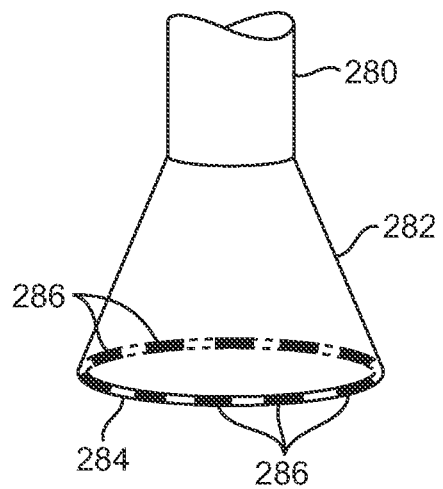


FIG. 22A

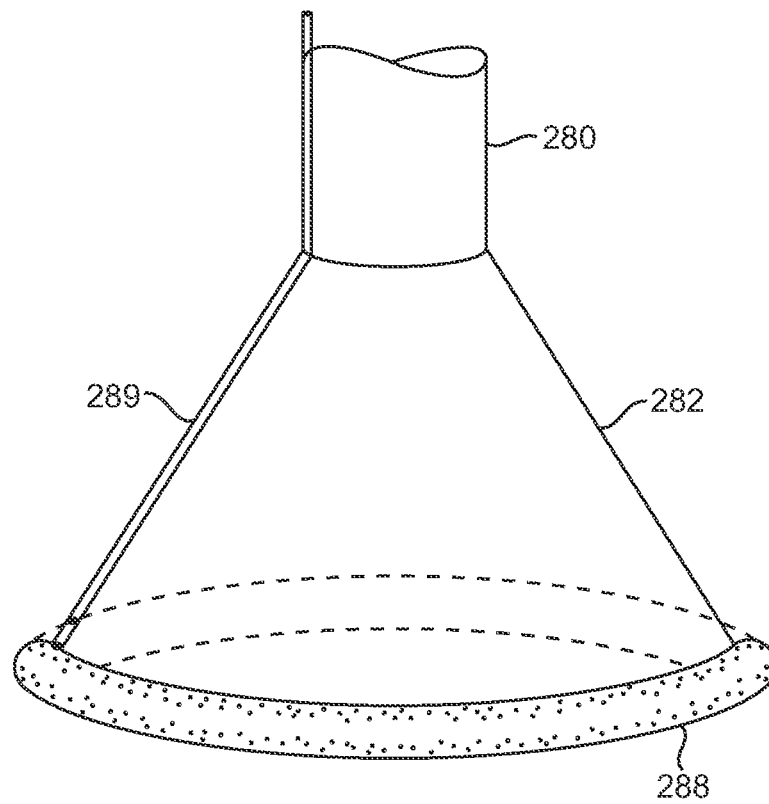


FIG. 22B

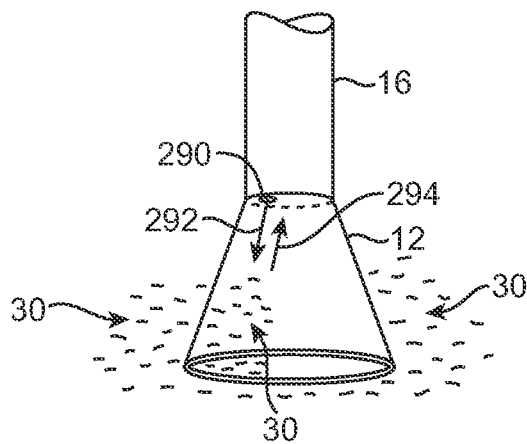


FIG. 23

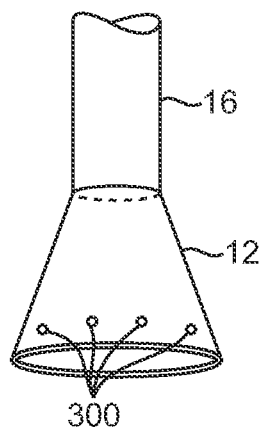


FIG. 24A

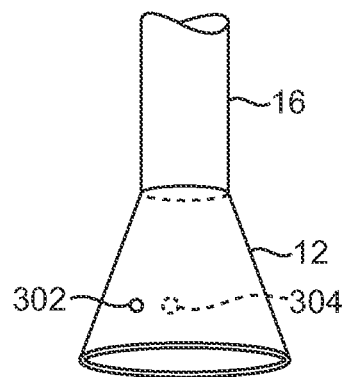


FIG. 24B



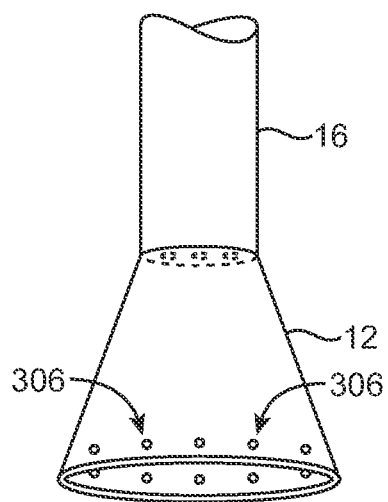


FIG. 25A

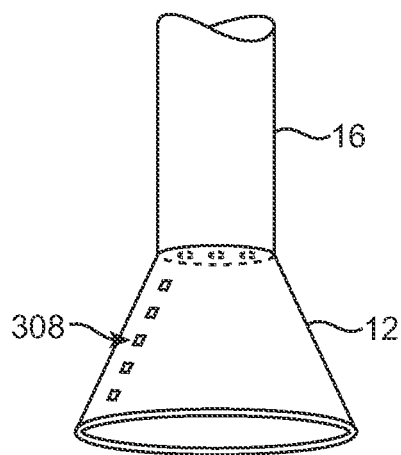


FIG. 25B

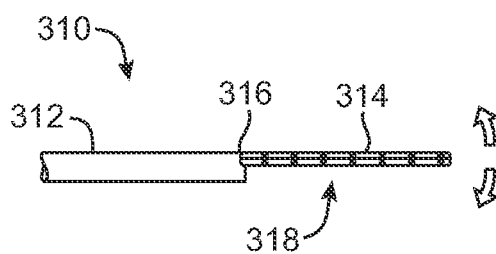


FIG. 26A

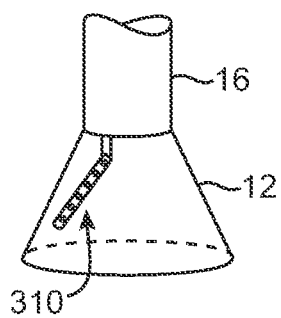


FIG. 26B

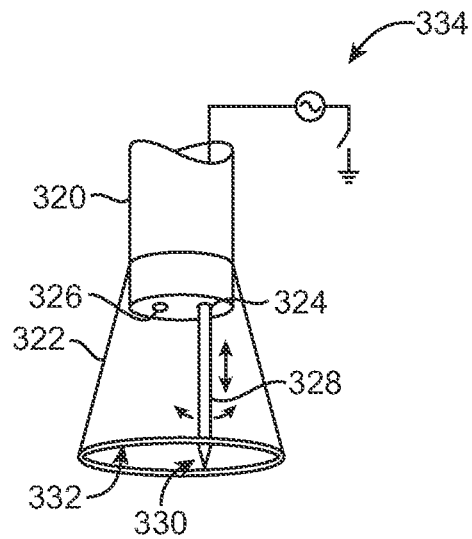


FIG. 27

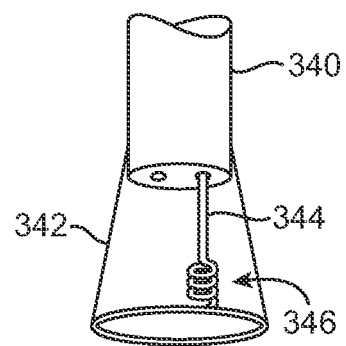


FIG. 28

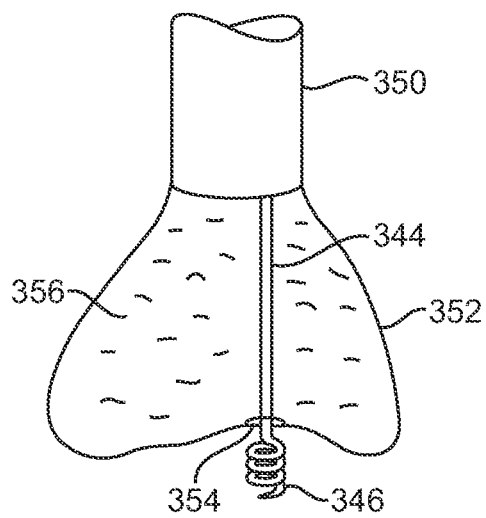


FIG. 29

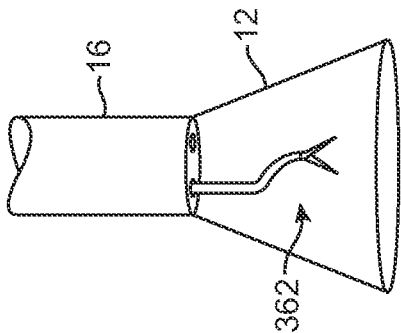


FIG. 30B

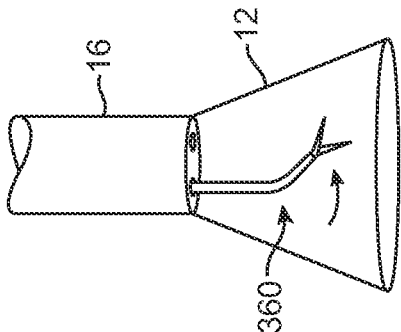


FIG. 30A

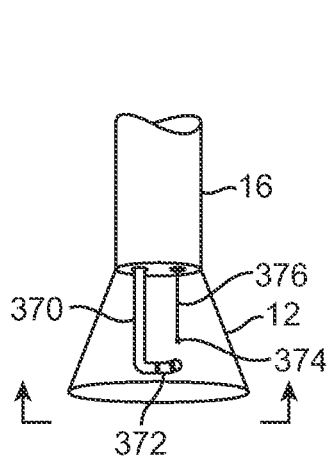


FIG. 31A

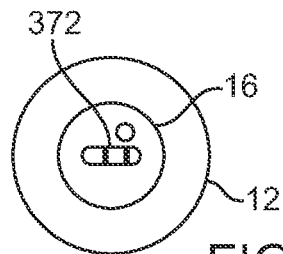


FIG. 31B

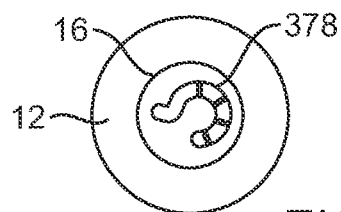


FIG. 31C

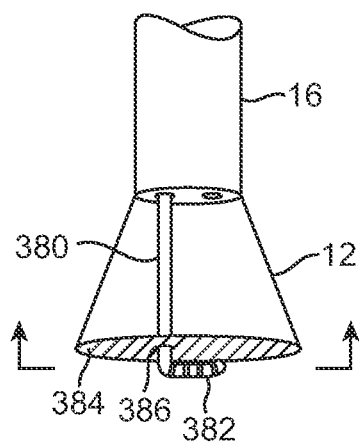


FIG. 32A

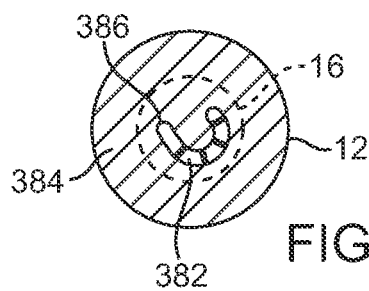


FIG. 32B

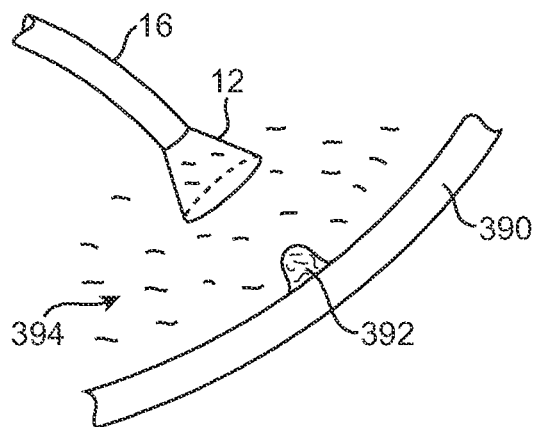


FIG. 33A

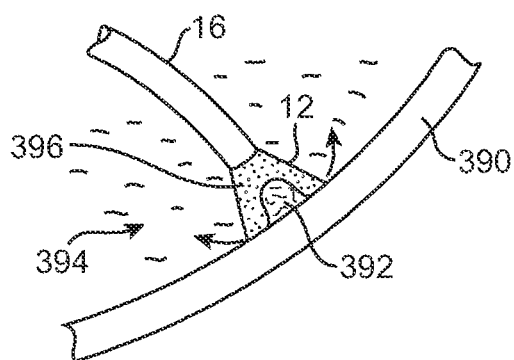


FIG. 33B

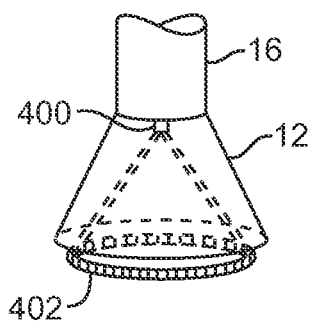


FIG. 34A

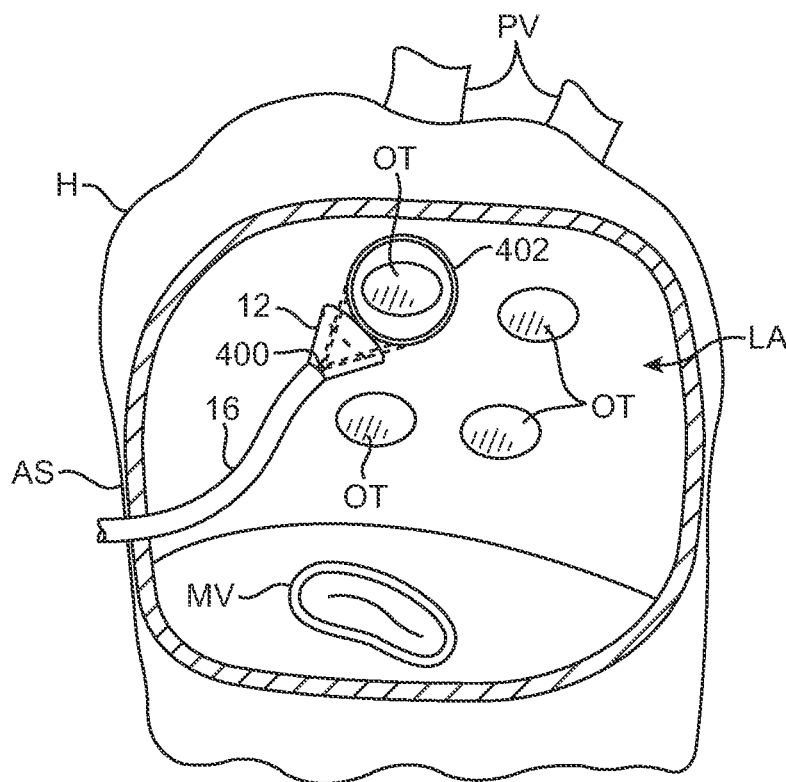


FIG. 34B

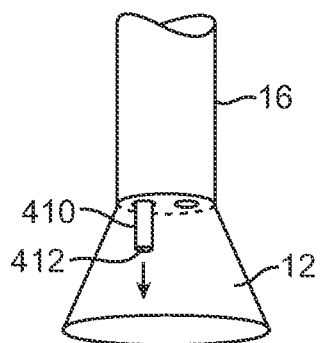


FIG. 35A

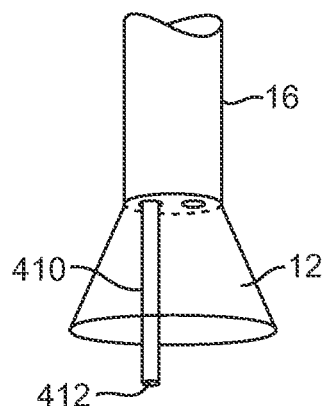


FIG. 35B

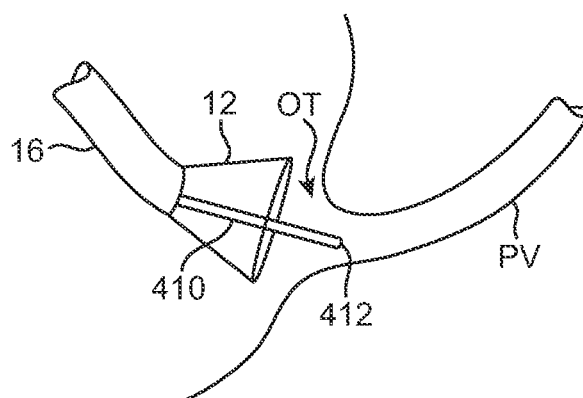


FIG. 35C



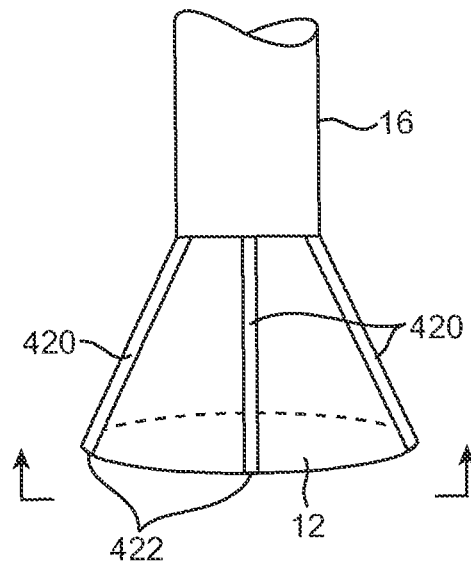


FIG. 36A

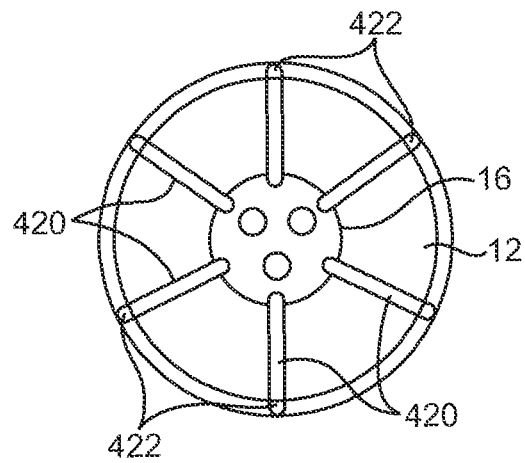


FIG. 36B

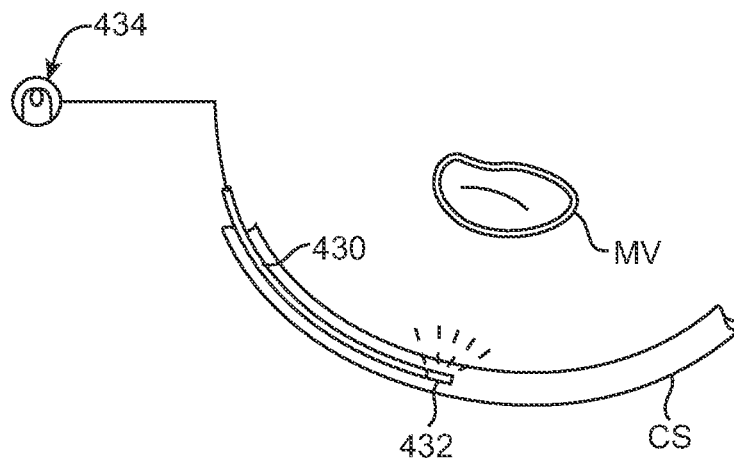


FIG. 37A

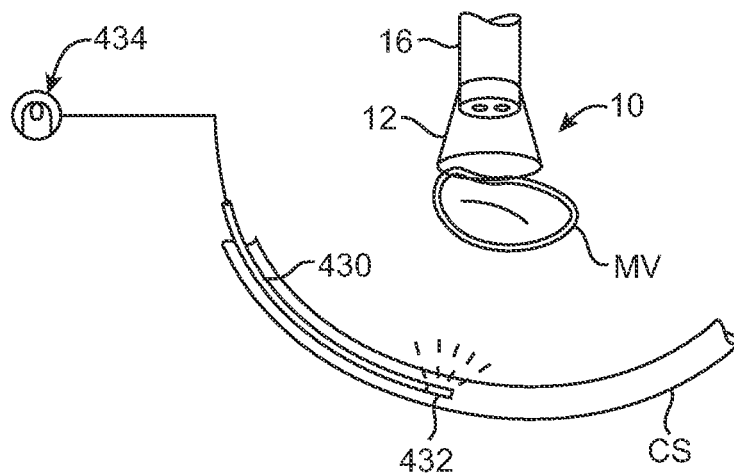


FIG. 37B

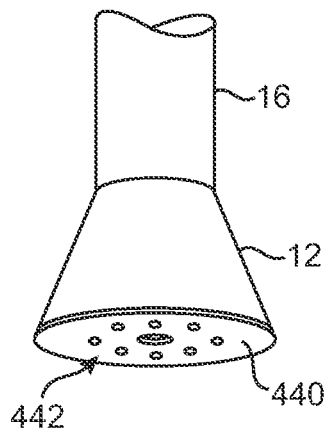


FIG. 38A

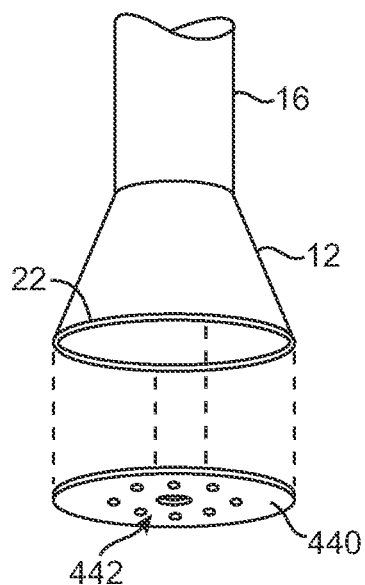


FIG. 38B

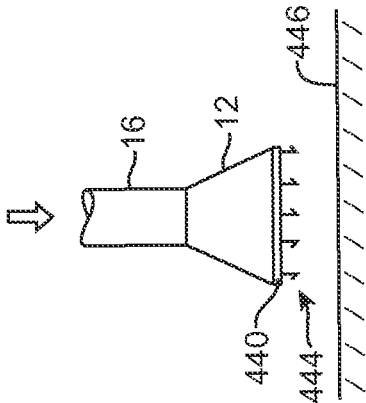


FIG. 39A

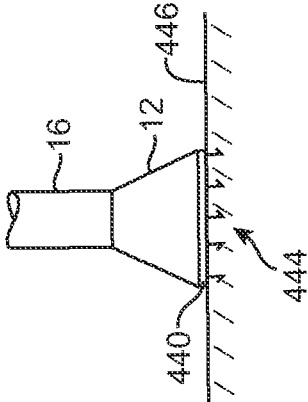


FIG. 39B

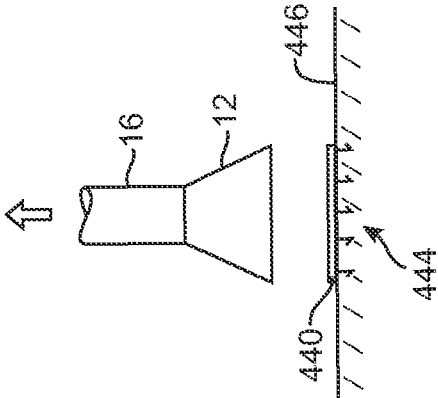


FIG. 39C

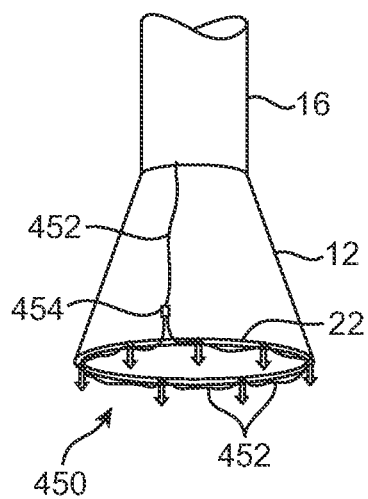


FIG. 40A

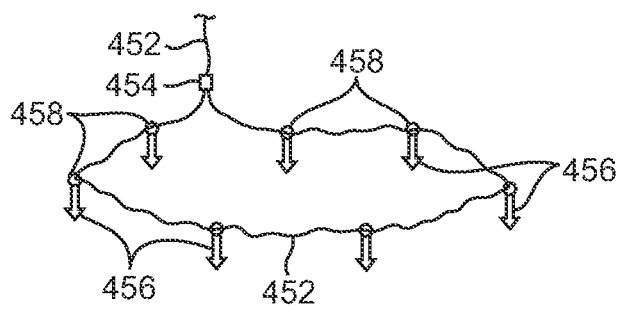


FIG. 40B

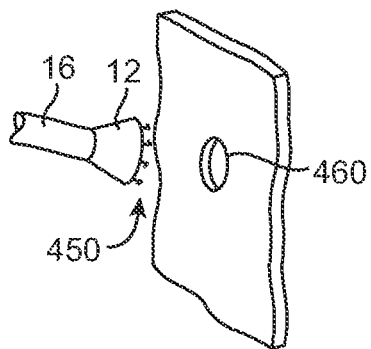


FIG. 41A

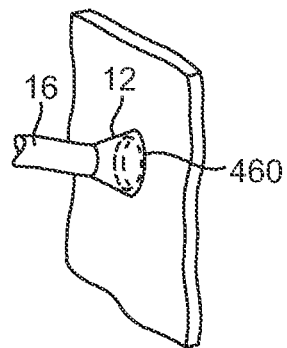


FIG. 41B

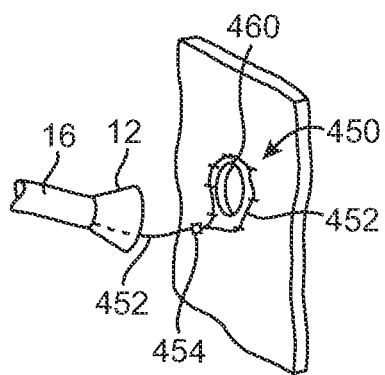


FIG. 41C

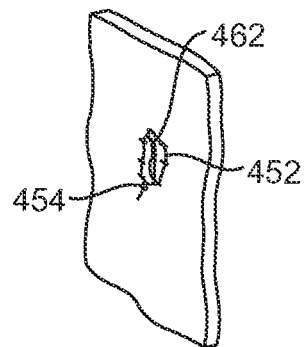


FIG. 41D

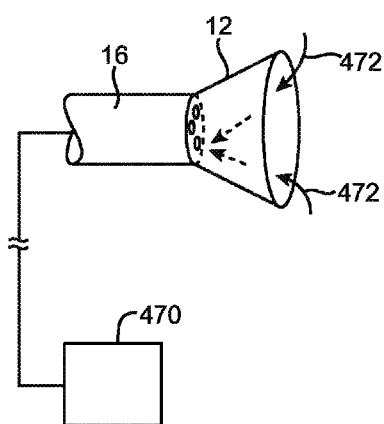


FIG. 42

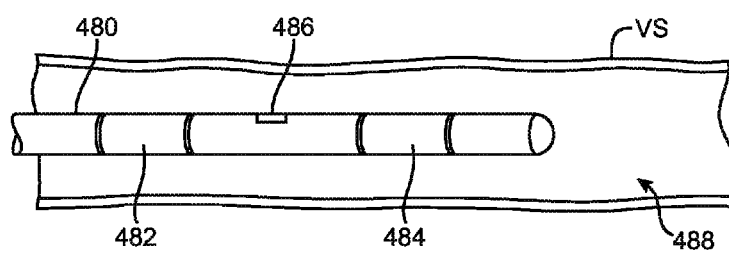


FIG. 43A

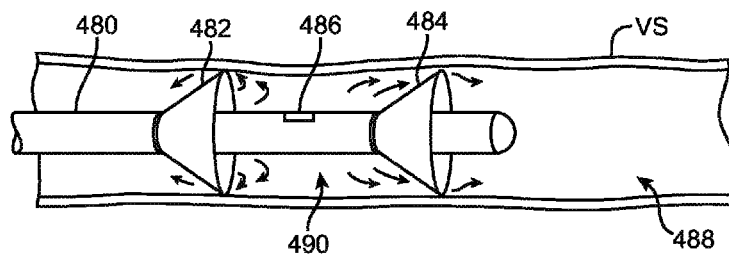


FIG. 43B



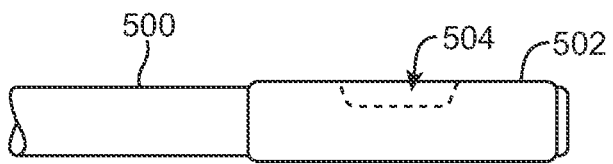


FIG. 44A



FIG. 44B

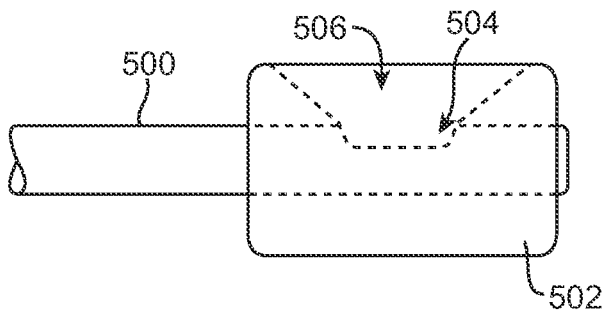


FIG. 45A

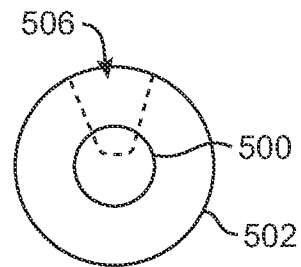


FIG. 45C

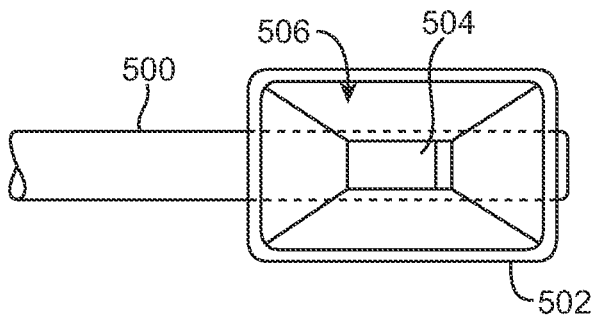


FIG. 45B

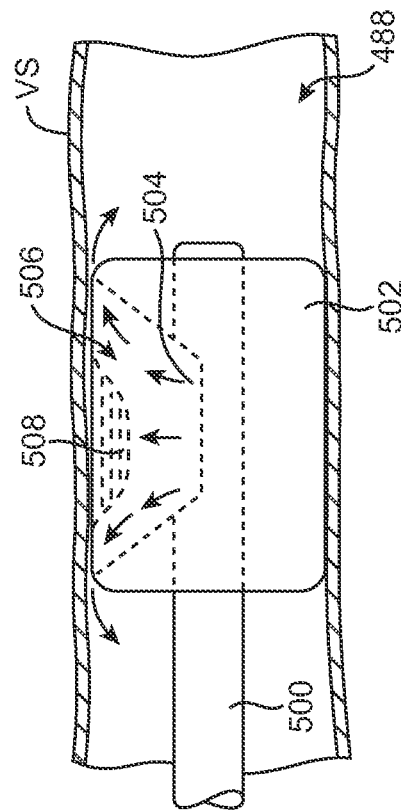


FIG. 46A

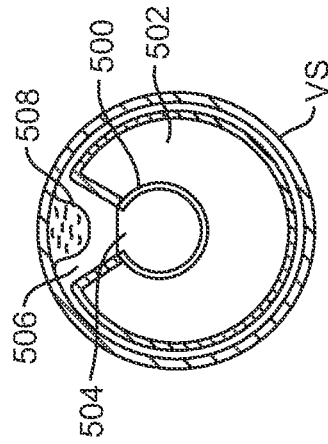


FIG. 46B

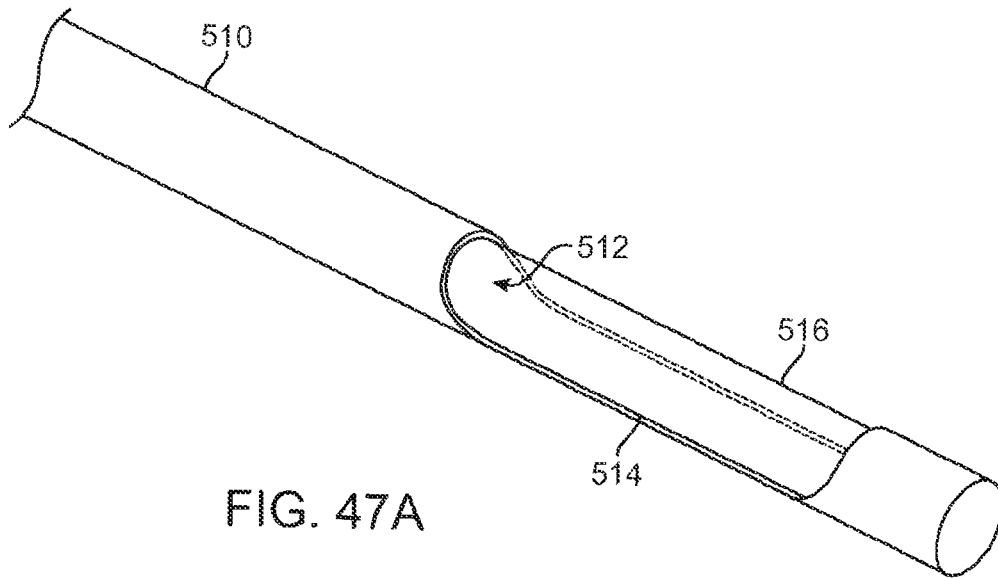


FIG. 47A

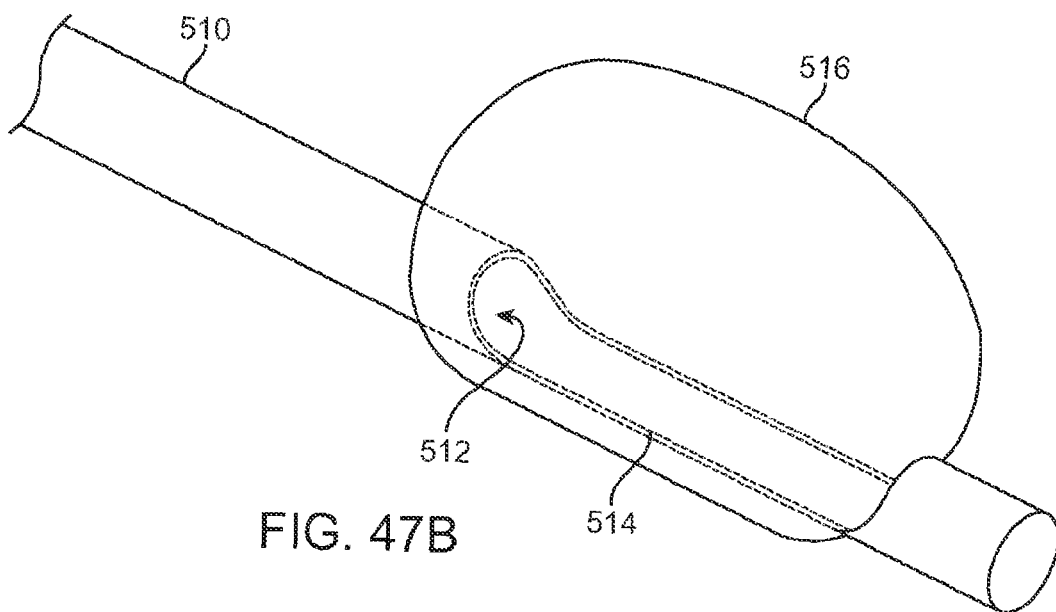


FIG. 47B

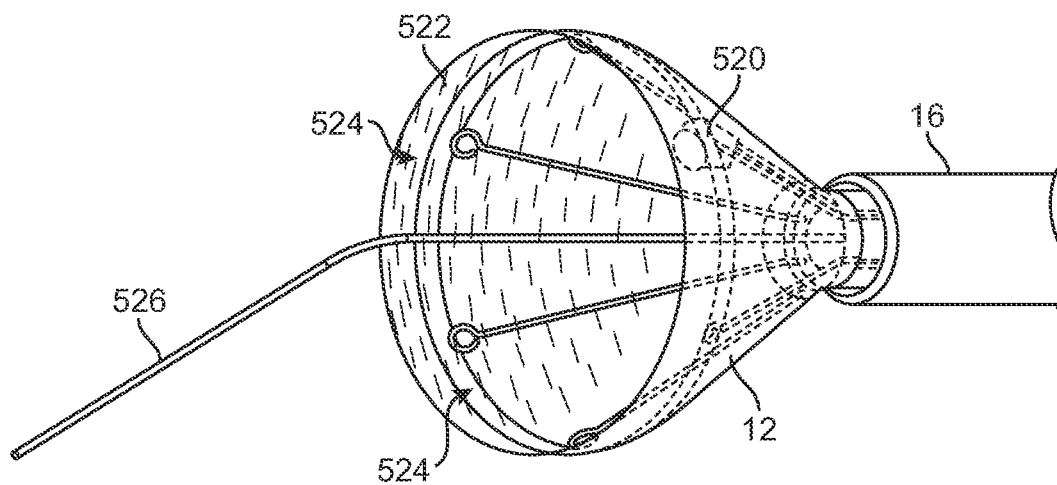


FIG. 48

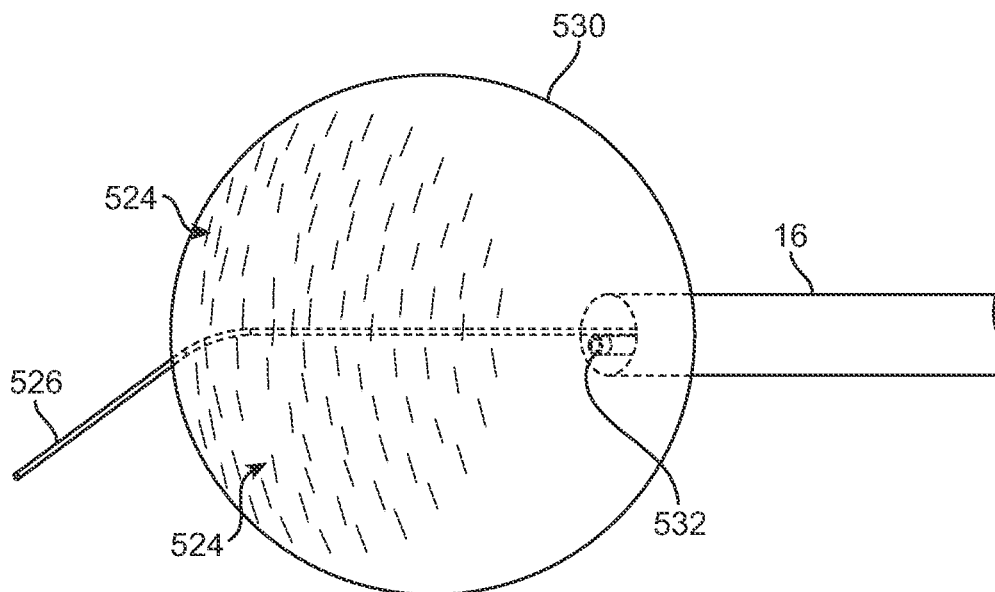


FIG. 49

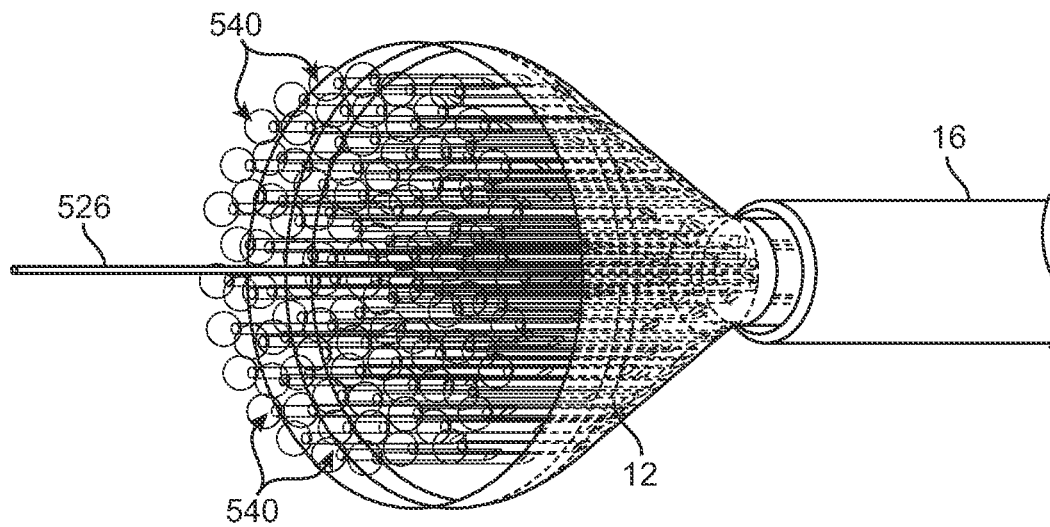


FIG. 50

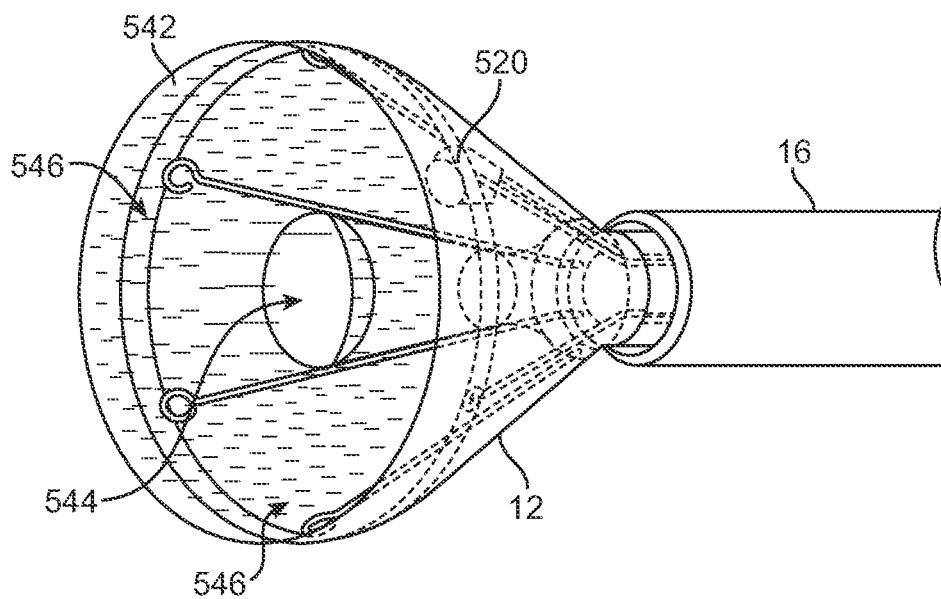


FIG. 51

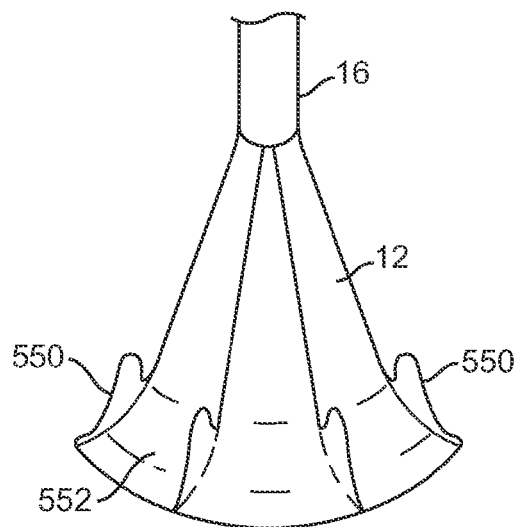


FIG. 52A

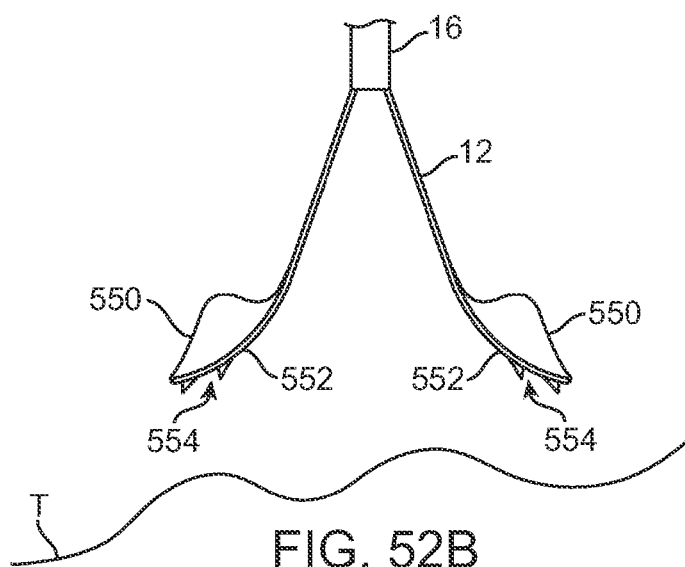


FIG. 52B

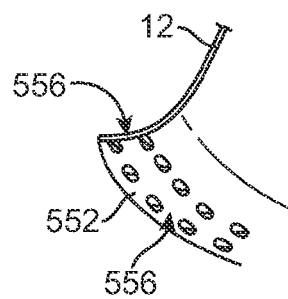


FIG. 52C

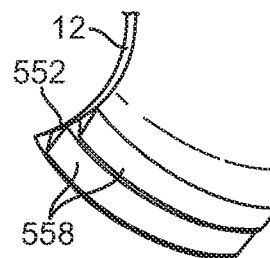


FIG. 52D

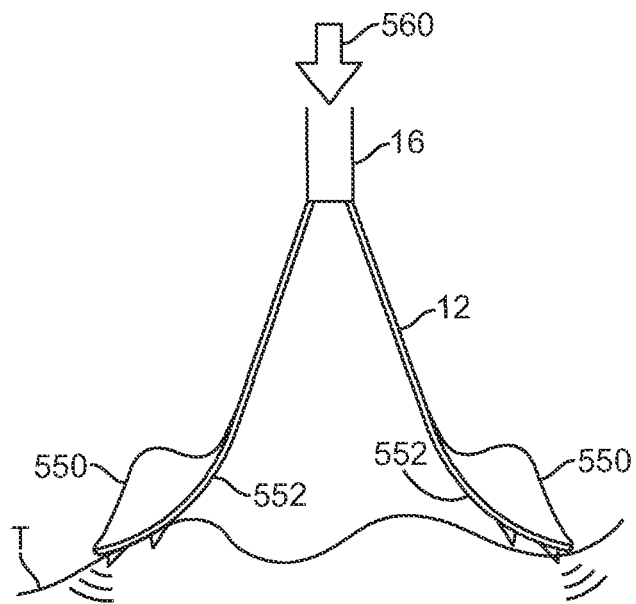


FIG. 53A

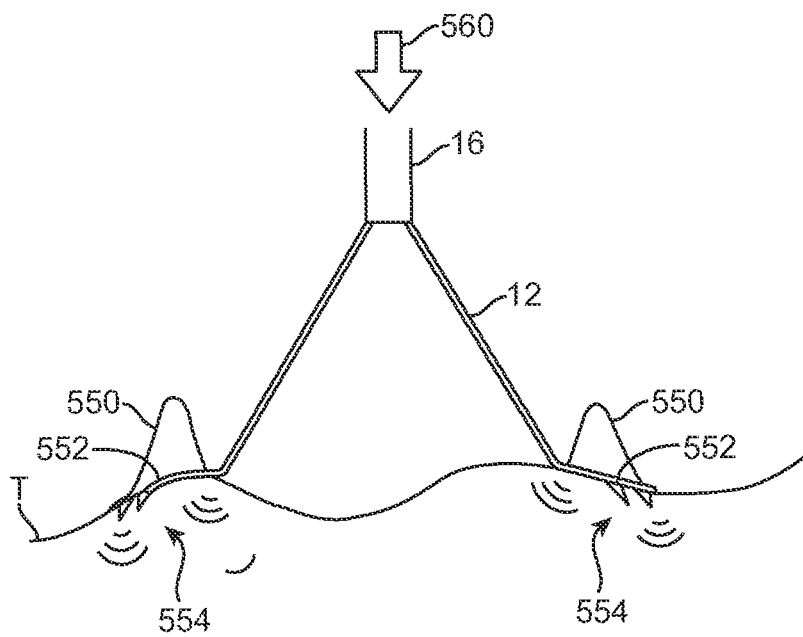


FIG. 53B

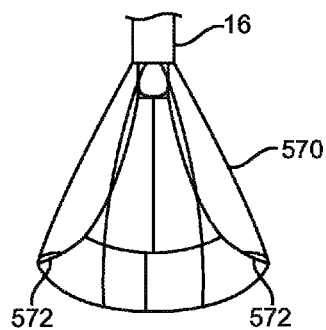


FIG. 54A

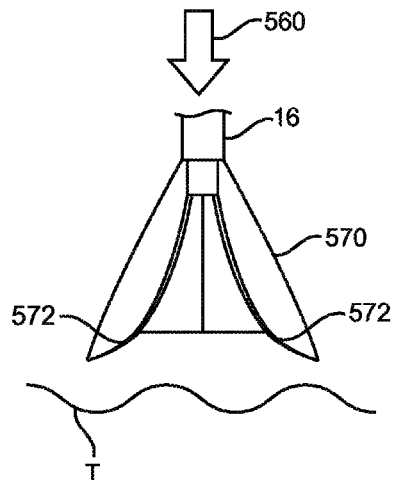


FIG. 54B

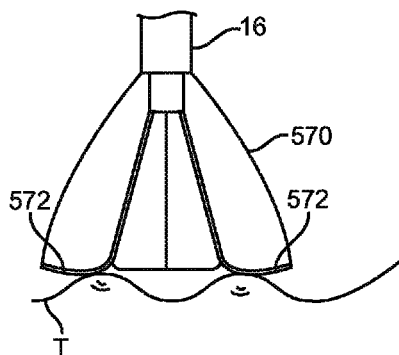


FIG. 54C

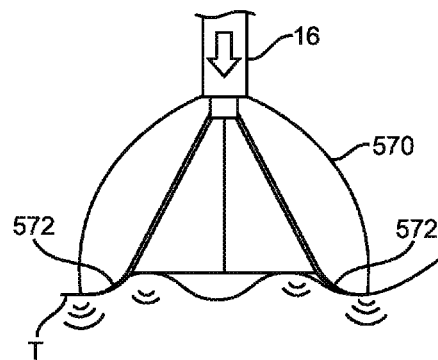


FIG. 54D



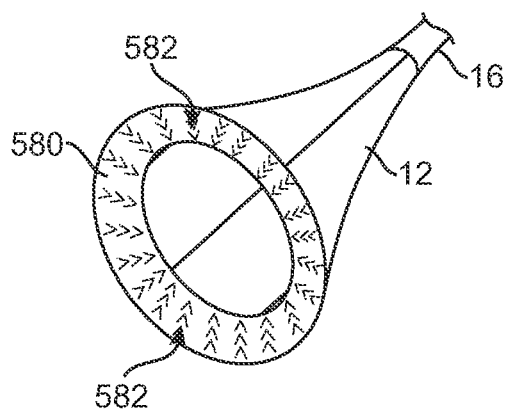


FIG. 55A

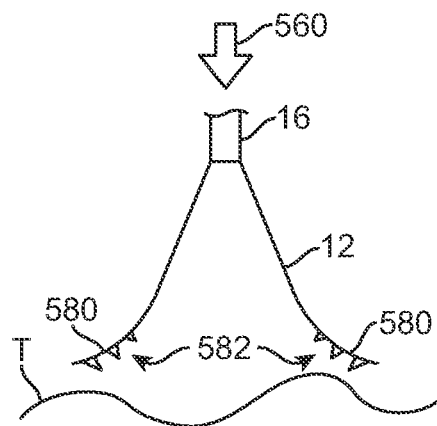


FIG. 55B

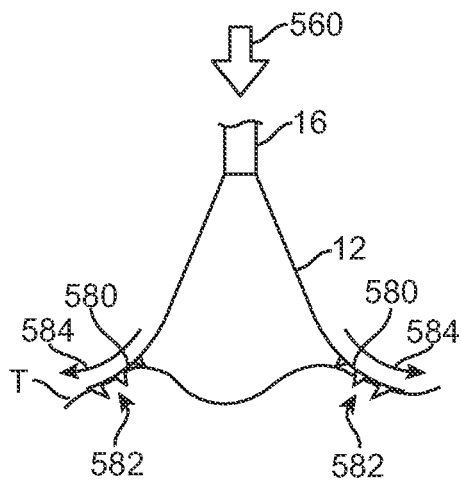


FIG. 55C

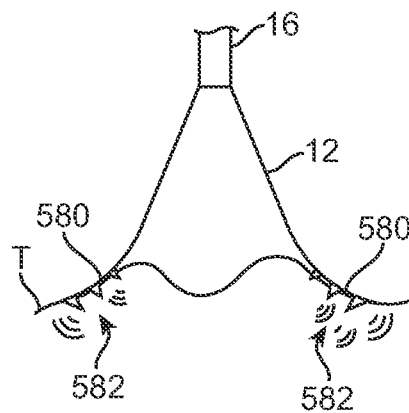


FIG. 55D

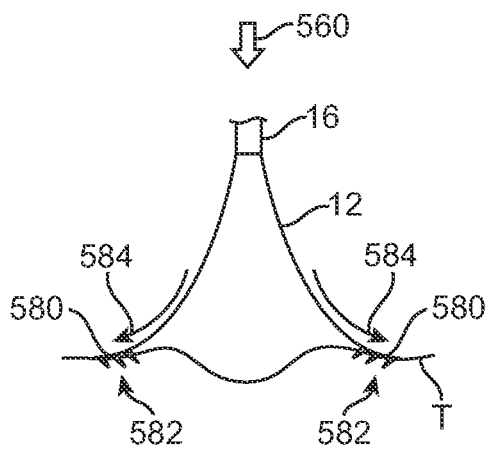


FIG. 56A

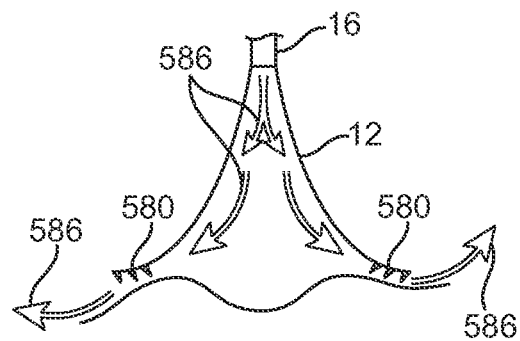


FIG. 56B

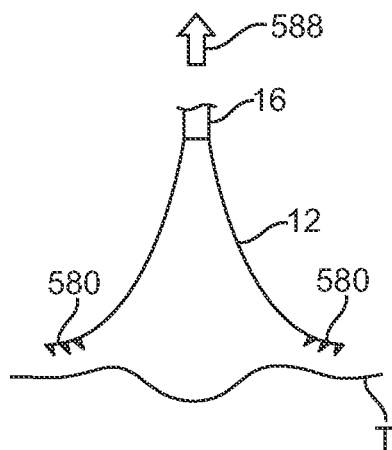


FIG. 56C

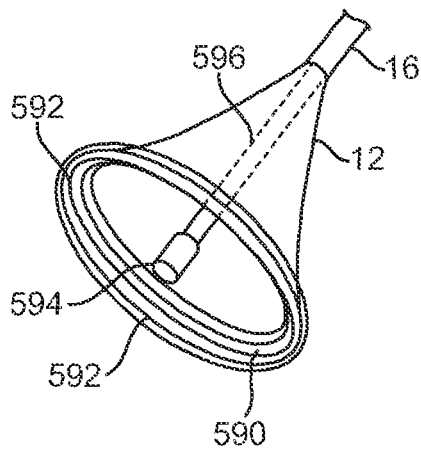


FIG. 57A

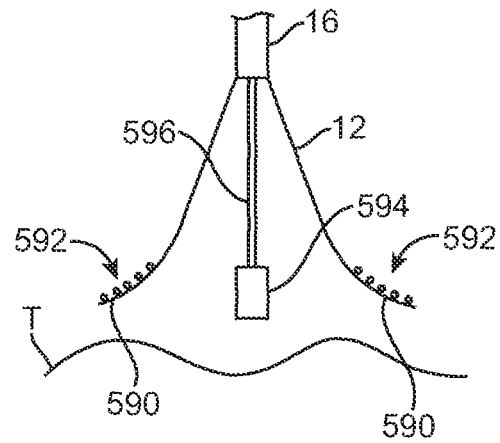


FIG. 57B

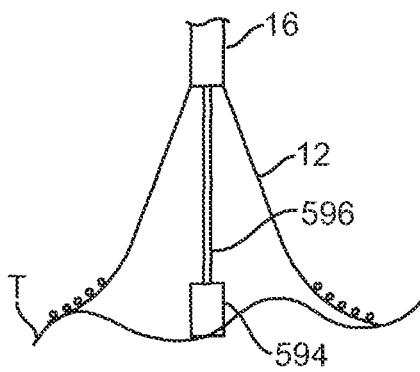


FIG. 57C

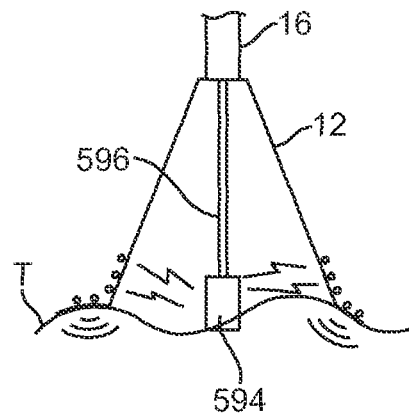


FIG. 57D

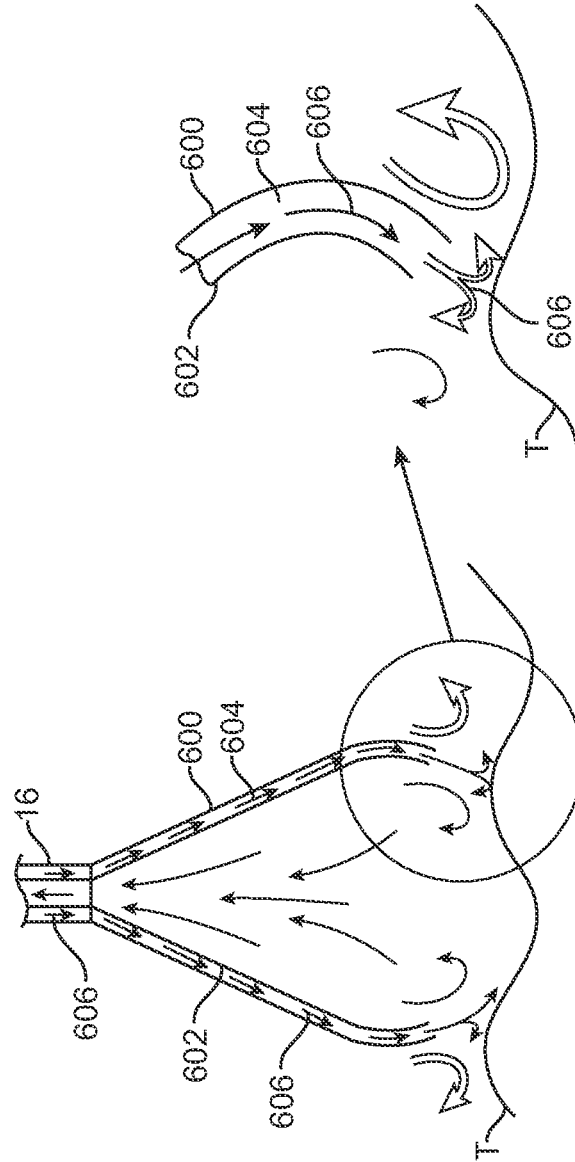
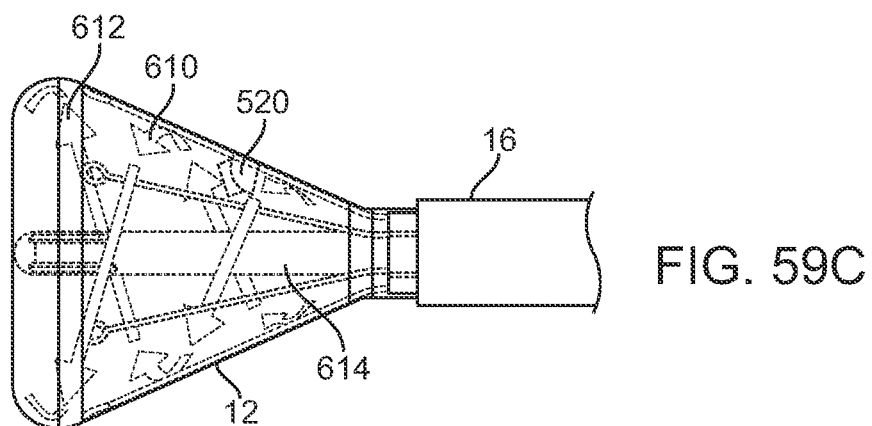
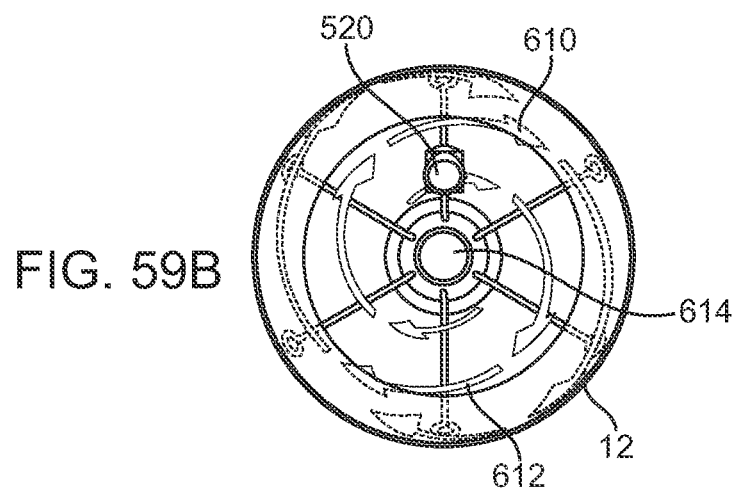
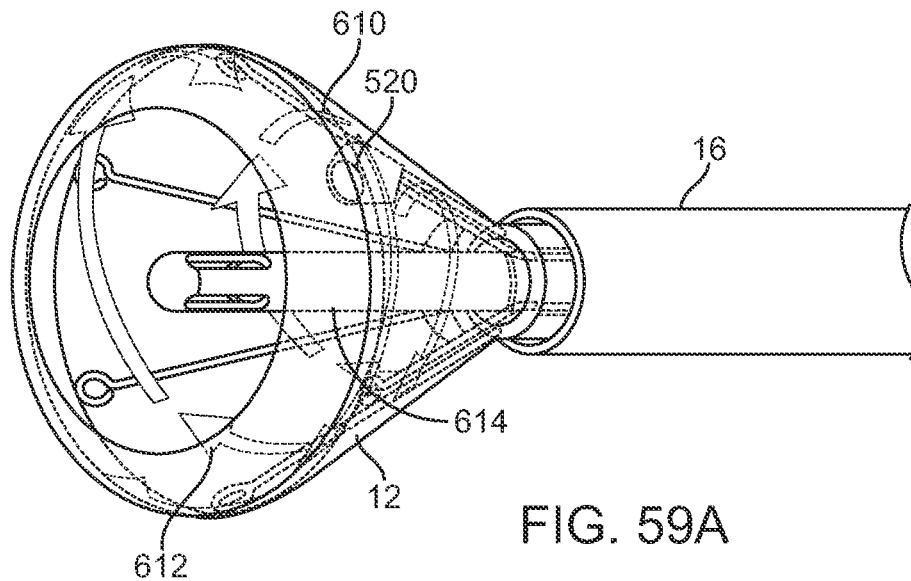


FIG. 58A

FIG. 58B



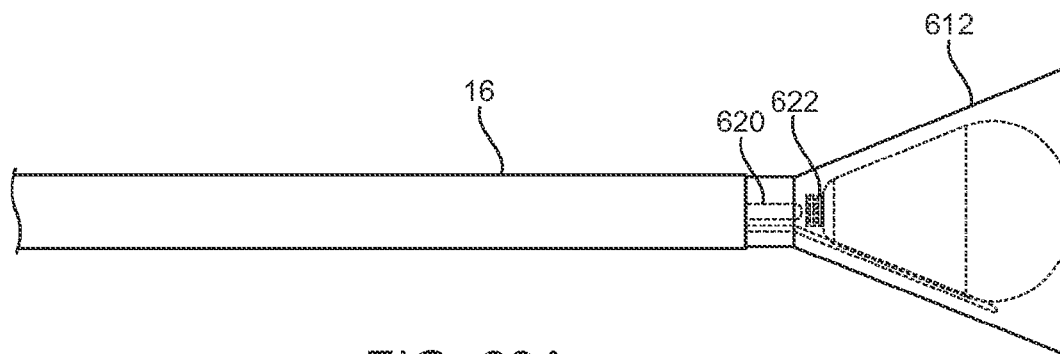


FIG. 60A

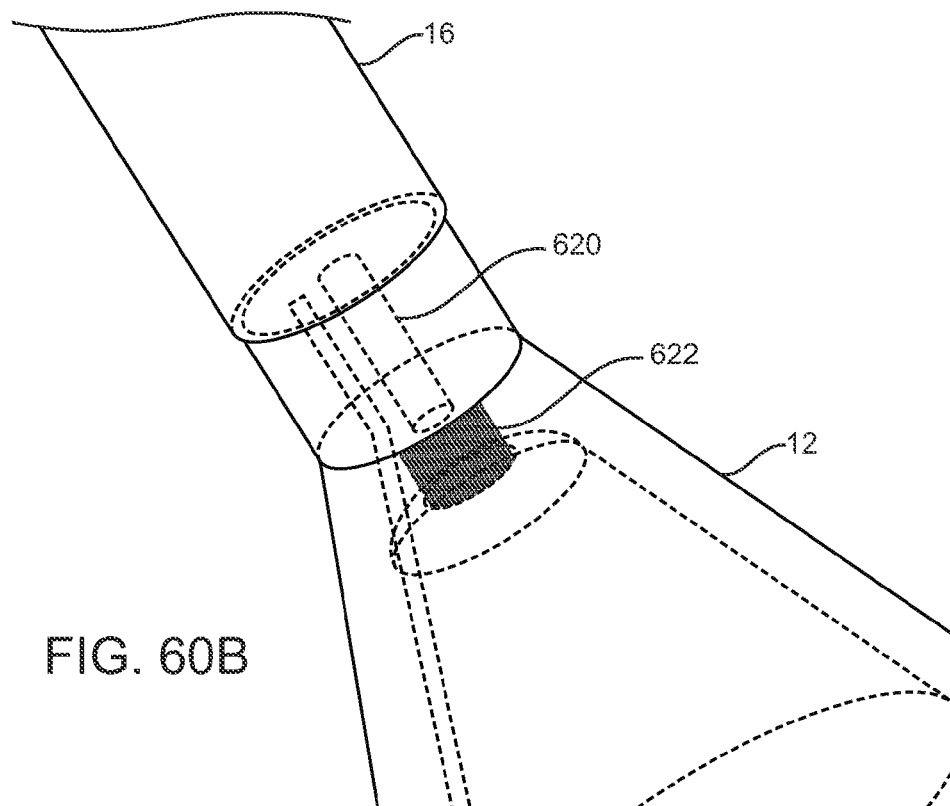


FIG. 60B

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## TISSUE VISUALIZATION DEVICE AND METHOD VARIATIONS

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 11/848,202, filed Aug. 30, 2007, which claims the benefit of provisional U.S. Application No. 60/824,418 and provisional U.S. Application No. 60/824,423 both filed Sep. 1, 2006 and is also a continuation-in-part of U.S. application Ser. No. 11/259,498 (now U.S. Pat. No. 7,860,555) and each of which is incorporated herein by reference in its entirety.

### FIELD OF THE INVENTION

The present invention relates generally to medical devices used for accessing, visualizing, and/or treating regions of tissue within a body. More particularly, the present invention relates to devices and methods for visualizing and/or manipulating tissue regions within a body lumen which are generally difficult to image because of surrounding opaque bodily fluids such as blood.

### BACKGROUND OF THE INVENTION

Conventional devices for visualizing interior regions of a body lumen are known. For example, ultrasound devices have been used to produce images from within a body in vivo. Ultrasound has been used both with and without contrast agents, which typically enhance ultrasound-derived images.

Other conventional methods have utilized catheters or probes having position sensors deployed within the body lumen, such as the interior of a cardiac chamber. These types of positional sensors are typically used to determine the movement of a cardiac tissue surface or the electrical activity within the cardiac tissue. When a sufficient number of points have been sampled by the sensors, a "map" of the cardiac tissue may be generated.

Another conventional device utilizes an inflatable balloon which is typically introduced intravascularly in a deflated state and then inflated against the tissue region to be examined. Imaging is typically accomplished by an optical fiber or other apparatus such as electronic chips for viewing the tissue through the membrane(s) of the inflated balloon. Moreover, the balloon must generally be inflated for imaging. Other conventional balloons utilize a cavity or depression formed at a distal end of the inflated balloon. This cavity or depression is pressed against the tissue to be examined and is flushed with a clear fluid to provide a clear pathway through the blood.

However, such imaging balloons have many inherent disadvantages. For instance, such balloons generally require that the balloon be inflated to a relatively large size which may undesirably displace surrounding tissue and interfere with fine positioning of the imaging system against the tissue. Moreover, the working area created by such inflatable balloons are generally cramped and limited in size. Furthermore, inflated balloons may be susceptible to pressure changes in the surrounding fluid. For example, if the environment surrounding the inflated balloon undergoes pressure changes, e.g., during systolic and diastolic pressure cycles in a beating heart, the constant pressure change may affect the inflated balloon volume and its positioning to produce unsteady or undesirable conditions for optimal tissue imaging.

Accordingly, these types of imaging modalities are generally unable to provide desirable images useful for sufficient

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diagnosis and therapy of the endoluminal structure, due in part to factors such as dynamic forces generated by the natural movement of the heart. Moreover, anatomic structures within the body can occlude or obstruct the image acquisition process. Also, the presence and movement of opaque bodily fluids such as blood generally make in vivo imaging of tissue regions within the heart difficult.

Other external imaging modalities are also conventionally utilized. For example, computed tomography (CT) and magnetic resonance imaging (MRI) are typical modalities which are widely used to obtain images of body lumens such as the interior chambers of the heart. However, such imaging modalities fail to provide real-time imaging for intra-operative therapeutic procedures. Fluoroscopic imaging, for instance, is widely used to identify anatomic landmarks within the heart and other regions of the body. However, fluoroscopy fails to provide an accurate image of the tissue quality or surface and also fails to provide for instrumentation for performing tissue manipulation or other therapeutic procedures upon the visualized tissue regions. In addition, fluoroscopy provides a shadow of the intervening tissue onto a plate or sensor when it may be desirable to view the intraluminal surface of the tissue to diagnose pathologies or to perform some form of therapy on it.

Thus, a tissue imaging system which is able to provide real-time in vivo images of tissue regions within body lumens such as the heart through opaque media such as blood and which also provide instruments for therapeutic procedures upon the visualized tissue are desirable.

### BRIEF SUMMARY OF THE INVENTION

A tissue imaging and manipulation apparatus that may be utilized for procedures within a body lumen, such as the heart, in which visualization of the surrounding tissue is made difficult, if not impossible, by medium contained within the lumen such as blood, is described below. Generally, such a tissue imaging and manipulation apparatus comprises an optional delivery catheter or sheath through which a deployment catheter and imaging hood may be advanced for placement against or adjacent to the tissue to be imaged.

The deployment catheter may define a fluid delivery lumen therethrough as well as an imaging lumen within which an optical imaging fiber or assembly may be disposed for imaging tissue. When deployed, the imaging hood may be expanded into any number of shapes, e.g., cylindrical, conical as shown, semi-spherical, etc., provided that an open area or field is defined by the imaging hood. The open area is the area within which the tissue region of interest may be imaged. The imaging hood may also define an atraumatic contact lip or edge for placement or abutment against the tissue region of interest. Moreover, the distal end of the deployment catheter or separate manipulatable catheters may be articulated through various controlling mechanisms such as push-pull wires manually or via computer control.

The deployment catheter may also be stabilized relative to the tissue surface through various methods. For instance, inflatable stabilizing balloons positioned along a length of the catheter may be utilized, or tissue engagement anchors may be passed through or along the deployment catheter for temporary engagement of the underlying tissue.

In operation, after the imaging hood has been deployed, fluid may be pumped at a positive pressure through the fluid delivery lumen until the fluid fills the open area completely and displaces any blood from within the open area. The fluid may comprise any biocompatible fluid, e.g., saline, water, plasma, Fluorinert™, etc., which is sufficiently transparent to

allow for relatively undistorted visualization through the fluid. The fluid may be pumped continuously or intermittently to allow for image capture by an optional processor which may be in communication with the assembly.

In an exemplary variation for imaging tissue surfaces within a heart chamber containing blood, the tissue imaging and treatment system may generally comprise a catheter body having a lumen defined therethrough, a visualization element disposed adjacent the catheter body, the visualization element having a field of view, a transparent fluid source in fluid communication with the lumen, and a barrier or membrane extendable from the catheter body to localize, between the visualization element and the field of view, displacement of blood by transparent fluid that flows from the lumen, and a piercing instrument translatable through the displaced blood for piercing into the tissue surface within the field of view.

The imaging hood may be formed into any number of configurations and the imaging assembly may also be utilized with any number of therapeutic tools which may be deployed through the deployment catheter.

More particularly in certain variations, the tissue visualization system may comprise components including the imaging hood, where the hood may further include a membrane having a main aperture and additional optional openings disposed over the distal end of the hood. An introducer sheath or the deployment catheter upon which the imaging hood is disposed may further comprise a steerable segment made of multiple adjacent links which are pivotably connected to one another and which may be articulated within a single plane or multiple planes. The deployment catheter itself may be comprised of a multiple lumen extrusion, such as a four-lumen catheter extrusion, which is reinforced with braided stainless steel fibers to provide structural support. The proximal end of the catheter may be coupled to a handle for manipulation and articulation of the system.

Variations of the tissue visualization system may further include mechanisms for facilitating and enhancing the sealing between the hood and the underlying tissue to be visualized and/or treated. For example, mechanisms may be utilized over a circumferentially disposed contact portion extending from the hood, e.g., biasing suspension members, projections, magnetic or electromagnetic elements, etc.

Additionally, other variations may include the inclusion of one-way valves over the surface of a balloon contained within the hood as well as multiple longitudinally disposed balloons positioned within the hood.

Further examples of the tissue visualization catheter systems which may be utilized are described in further detail in U.S. Pat. App. 2006/0184048 A1, which is incorporated herein by reference in its entirety.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A shows a side view of one variation of a tissue imaging apparatus during deployment from a sheath or delivery catheter.

FIG. 1B shows the deployed tissue imaging apparatus of FIG. 1A having an optionally expandable hood or sheath attached to an imaging and/or diagnostic catheter.

FIG. 1C shows an end view of a deployed imaging apparatus.

FIGS. 1D to 1F show the apparatus of FIGS. 1A to 1C with an additional lumen, e.g., for passage of a guidewire therethrough.

FIGS. 2A and 2B show one example of a deployed tissue imager positioned against or adjacent to the tissue to be

imaged and a flow of fluid, such as saline, displacing blood from within the expandable hood.

FIG. 3A shows an articulatable imaging assembly which may be manipulated via push-pull wires or by computer control.

FIGS. 3B and 3C show steerable instruments, respectively, where an articulatable delivery catheter may be steered within the imaging hood or a distal portion of the deployment catheter itself may be steered.

FIGS. 4A to 4C show side and cross-sectional end views, respectively, of another variation having an off-axis imaging capability.

FIG. 5 shows an illustrative view of an example of a tissue imager advanced intravascularly within a heart for imaging tissue regions within an atrial chamber.

FIGS. 6A to 6C illustrate deployment catheters having one or more optional inflatable balloons or anchors for stabilizing the device during a procedure.

FIGS. 7A and 7B illustrate a variation of an anchoring mechanism such as a helical tissue piercing device for temporarily stabilizing the imaging hood relative to a tissue surface.

FIG. 7C shows another variation for anchoring the imaging hood having one or more tubular support members integrated with the imaging hood; each support members may define a lumen therethrough for advancing a helical tissue anchor within.

FIG. 8A shows an illustrative example of one variation of how a tissue imager may be utilized with an imaging device.

FIG. 8B shows a further illustration of a hand-held variation of the fluid delivery and tissue manipulation system.

FIGS. 9A to 9C illustrate an example of capturing several images of the tissue at multiple regions.

FIGS. 10A and 10B show charts illustrating how fluid pressure within the imaging hood may be coordinated with the surrounding blood pressure; the fluid pressure in the imaging hood may be coordinated with the blood pressure or it may be regulated based upon pressure feedback from the blood.

FIG. 11A shows a side view of another variation of a tissue imager having an imaging balloon within an expandable hood.

FIG. 11B shows another variation of a tissue imager utilizing a translucent or transparent imaging balloon.

FIG. 12A shows another variation in which a flexible expandable or distensible membrane may be incorporated within the imaging hood to alter the volume of fluid dispensed.

FIGS. 12B and 12C show another variation in which the imaging hood may be partially or selectively deployed from the catheter to alter the area of the tissue being visualized as well as the volume of the dispensed fluid.

FIGS. 13A and 13B show exemplary side and cross-sectional views, respectively, of another variation in which the injected fluid may be drawn back into the device for minimizing fluid input into a body being treated.

FIGS. 14A to 14D show various configurations and methods for configuring an imaging hood into a low-profile for delivery and/or deployment.

FIGS. 15A and 15B show an imaging hood having an helically expanding frame or support.

FIGS. 16A and 16B show another imaging hood having one or more hood support members, which are pivotably attached at their proximal ends to deployment catheter, integrated with a hood membrane.

FIGS. 17A and 17B show yet another variation of the imaging hood having at least two or more longitudinally



positioned support members supporting the imaging hood membrane where the support members are movable relative to one another via a torquing or pulling or pushing force.

FIGS. 18A and 18B show another variation where a distal portion of the deployment catheter may have several pivoting members which form a tubular shape in its low profile configuration.

FIGS. 19A and 19B show another variation where the distal portion of deployment catheter may be fabricated from a flexible metallic or polymeric material to form a radially expanding hood.

FIGS. 20A and 20B show another variation where the imaging hood may be formed from a plurality of overlapping hood members which overlies one another in an overlapping pattern.

FIGS. 21A and 21B show another example of an expandable hood which is highly conformable against tissue anatomy with varying geography.

FIG. 22A shows yet another example of an expandable hood having a number of optional electrodes placed about the contact edge or lip of the hood for sensing tissue contact or detecting arrhythmias.

FIG. 22B shows another variation for conforming the imaging hood against the underlying tissue where an inflatable contact edge may be disposed around the circumference of the imaging hood.

FIG. 23 shows a variation of the system which may be instrumented with a transducer for detecting the presence of blood seeping back into the imaging hood.

FIGS. 24A and 24B show variations of the imaging hood instrumented with sensors for detecting various physical parameters; the sensors may be instrumented around the outer surface of the imaging hood and also within the imaging hood.

FIGS. 25A and 25B show a variation where the imaging hood may have one or more LEDs over the hood itself for providing illumination of the tissue to be visualized.

FIGS. 26A and 26B show another variation in which a separate illumination tool having one or more LEDs mounted thereon may be utilized within the imaging hood.

FIG. 27 shows one example of how a therapeutic tool may be advanced through the tissue imager for treating a tissue region of interest.

FIG. 28 shows another example of a helical therapeutic tool for treating the tissue region of interest.

FIG. 29 shows a variation of how a therapeutic tool may be utilized with an expandable imaging balloon.

FIGS. 30A and 30B show alternative configurations for therapeutic instruments which may be utilized; one variation is shown having an angled instrument arm and another variation is shown with an off-axis instrument arm.

FIGS. 31A to 31C show side and end views, respectively, of an imaging system which may be utilized with an ablation probe.

FIGS. 32A and 32B show side and end views, respectively, of another variation of the imaging hood with an ablation probe, where the imaging hood may be enclosed for regulating a temperature of the underlying tissue.

FIGS. 33A and 33B show an example in which the imaging fluid itself may be altered in temperature to facilitate various procedures upon the underlying tissue.

FIGS. 34A and 34B show an example of a laser ring generator which may be utilized with the imaging system and an example for applying the laser ring generator within the left atrium of a heart for treating atrial fibrillation.

FIGS. 35A to 35C show an example of an extendible cannula generally comprising an elongate tubular member which

may be positioned within the deployment catheter during delivery and then projected distally through the imaging hood and optionally beyond.

FIGS. 36A and 36B show side and end views, respectively, of an imaging hood having one or more tubular support members integrated with the hood for passing instruments or tools therethrough for treatment upon the underlying tissue.

FIGS. 37A and 37B illustrate how an imaging device may be guided within a heart chamber to a region of interest utilizing a lighted probe positioned temporarily within, e.g., a lumen of the coronary sinus.

FIGS. 38A and 38B show an imaging hood having a removable disk-shaped member for implantation upon the tissue surface.

FIGS. 39A to 39C show one method for implanting the removable disk of FIGS. 38A and 38B.

FIGS. 40A and 40B illustrate an imaging hood having a deployable anchor assembly attached to the tissue contact edge and an assembly view of the anchors and the suture or wire connected to the anchors, respectively.

FIGS. 41A to 41D show one method for deploying the anchor assembly of FIGS. 40A and 40B for closing an opening or wound.

FIG. 42 shows another variation in which the imaging system may be fluidly coupled to a dialysis unit for filtering a patient's blood.

FIGS. 43A and 43B show a variation of the deployment catheter having a first deployable hood and a second deployable hood positioned distal to the first hood; the deployment catheter may also have a side-viewing imaging element positioned between the first and second hoods for imaging tissue between the expanded hoods.

FIGS. 44A and 44B show side and end views, respectively, of a deployment catheter having a side-imaging balloon in an un-inflated low-profile configuration.

FIGS. 45A to 45C show side, top, and end views, respectively, of the inflated balloon of FIGS. 44A and 44B defining a visualization field in the inflated balloon.

FIGS. 46A and 46B show side and cross-sectional end views, respectively, for one method of use in visualizing a lesion upon a vessel wall within the visualization field of the inflated balloon from FIGS. 45A to 45C.

FIGS. 47A and 47B shows perspective views of an elongate shaft having a balloon inflatable along a side surface near or at a distal end of the shaft.

FIG. 48 shows a perspective view of a tissue visualization catheter with multiple one-way slit valves defined over a distal surface of an inflated balloon positioned within a hood.

FIG. 49 shows a perspective view of a balloon catheter with multiple one-way slit valves defined over a distal surface of an inflated balloon.

FIG. 50 shows a perspective view of yet another variation of a tissue visualization catheter having multiple elongated balloons inflatable longitudinally within the hood.

FIG. 51 shows a perspective view of yet another variation of a tissue visualization catheter defining a unidirectional frictional surface over a distal surface of an inflatable balloon positioned within the hood.

FIGS. 52A and 52B show perspective and cross-sectional side views of another variation of the hood having one or more biasing suspension elements positioned about a circumference of the distal end of the hood.

FIGS. 52C and 52D show detail perspective views of examples of projections extending from the contact portion configured as extrusions or flap members, respectively, for facilitating contact between the hood and the underlying tissue.

FIGS. 53A and 53B show partial cross-sectional side views illustrating the biasing suspension elements in a relaxed configuration prior to and after placement against the tissue surface, respectively.

FIGS. 54A to 54D illustrate another variation of the tissue visualization catheter having a strut or scaffold frame made from a shape memory material.

FIGS. 55A to 55D illustrate yet another variation of the tissue visualization catheter having a plurality of barbs or projections around the contact portion of the hood for facilitating sealing against the tissue surface.

FIGS. 56A to 56C illustrate a method for disengaging and removing the hood of FIG. 55A from the tissue surface.

FIGS. 57A to 57D illustrate yet another variation of the having an electromagnetic ring or members positioned about the hood and a magnet positioned within the hood for gripping against the tissue to facilitate a contiguous seal against the tissue.

FIGS. 58A and 58B show cross sectional side views of a variation having an annular fluid injection channel which functions to produce a liquid seal or curtain against the tissue surface.

FIGS. 59A to 59C show perspective, end, and side views, respectively, of another variation in which the infused clearing fluid may be injected in a spiral manner within the hood.

FIGS. 60A and 60B show side and perspective views, respectively, of a tissue visualization catheter having a cleaning brush integrated within the hood.

#### DETAILED DESCRIPTION OF THE INVENTION

A tissue-imaging and manipulation apparatus described below is able to provide real-time images in vivo of tissue regions within a body lumen such as a heart, which is filled with blood flowing dynamically therethrough and is also able to provide intravascular tools and instruments for performing various procedures upon the imaged tissue regions. Such an apparatus may be utilized for many procedures, e.g., facilitating transeptal access to the left atrium, cannulating the coronary sinus, diagnosis of valve regurgitation/stenosis, valvuloplasty, atrial appendage closure, arrhythmogenic focus ablation, among other procedures.

One variation of a tissue access and imaging apparatus is shown in the detail perspective views of FIGS. 1A to 1C. As shown in FIG. 1A, tissue imaging and manipulation assembly 10 may be delivered intravascularly through the patient's body in a low-profile configuration via a delivery catheter or sheath 14. In the case of treating tissue, such as the mitral valve located at the outflow tract of the left atrium of the heart, it is generally desirable to enter or access the left atrium while minimizing trauma to the patient. To non-operatively effect such access, one conventional approach involves puncturing the intra-atrial septum from the right atrial chamber to the left atrial chamber in a procedure commonly called a transeptal procedure or septostomy. For procedures such as percutaneous valve repair and replacement, transeptal access to the left atrial chamber of the heart may allow for larger devices to be introduced into the venous system than can generally be introduced percutaneously into the arterial system.

When the imaging and manipulation assembly 10 is ready to be utilized for imaging tissue, imaging hood 12 may be advanced relative to catheter 14 and deployed from a distal opening of catheter 14, as shown by the arrow. Upon deployment, imaging hood 12 may be unconstrained to expand or open into a deployed imaging configuration, as shown in FIG. 1B. Imaging hood 12 may be fabricated from a variety of pliable or conformable biocompatible material including but

not limited to, e.g., polymeric, plastic, or woven materials. One example of a woven material is Kevlar® (E. I. du Pont de Nemours, Wilmington, Del.), which is an aramid and which can be made into thin, e.g., less than 0.001 in., materials which maintain enough integrity for such applications described herein. Moreover, the imaging hood 12 may be fabricated from a translucent or opaque material and in a variety of different colors to optimize or attenuate any reflected lighting from surrounding fluids or structures, i.e., anatomical or mechanical structures or instruments. In either case, imaging hood 12 may be fabricated into a uniform structure or a scaffold-supported structure, in which case a scaffold made of a shape memory alloy, such as Nitinol, or a spring steel, or plastic, etc., may be fabricated and covered with the polymeric, plastic, or woven material. Hence, imaging hood 12 may comprise any of a wide variety of barriers or membrane structures, as may generally be used to localize displacement of blood or the like from a selected volume of a body lumen or heart chamber. In exemplary embodiments, a volume within an inner surface 13 of imaging hood 12 will be significantly less than a volume of the hood 12 between inner surface 13 and outer surface 11.

Imaging hood 12 may be attached at interface 24 to a deployment catheter 16 which may be translated independently of deployment catheter or sheath 14. Attachment of interface 24 may be accomplished through any number of conventional methods. Deployment catheter 16 may define a fluid delivery lumen 18 as well as an imaging lumen 20 within which an optical imaging fiber or assembly may be disposed for imaging tissue. When deployed, imaging hood 12 may expand into any number of shapes, e.g., cylindrical, conical as shown, semi-spherical, etc., provided that an open area or field 26 is defined by imaging hood 12. The open area 26 is the area within which the tissue region of interest may be imaged. Imaging hood 12 may also define an atraumatic contact lip or edge 22 for placement or abutment against the tissue region of interest. Moreover, the diameter of imaging hood 12 at its maximum fully deployed diameter, e.g., at contact lip or edge 22, is typically greater relative to a diameter of the deployment catheter 16 (although a diameter of contact lip or edge 22 may be made to have a smaller or equal diameter of deployment catheter 16). For instance, the contact edge diameter may range anywhere from 1 to 5 times (or even greater, as practicable) a diameter of deployment catheter 16. FIG. 1C shows an end view of the imaging hood 12 in its deployed configuration. Also shown are the contact lip or edge 22 and fluid delivery lumen 18 and imaging lumen 20.

The imaging and manipulation assembly 10 may additionally define a guidewire lumen therethrough, e.g., a concentric or eccentric lumen, as shown in the side and end views, respectively, of FIGS. 1D to 1F. The deployment catheter 16 may define guidewire lumen 19 for facilitating the passage of the system over or along a guidewire 17, which may be advanced intravascularly within a body lumen. The deployment catheter 16 may then be advanced over the guidewire 17, as generally known in the art.

In operation, after imaging hood 12 has been deployed, as in FIG. 1B, and desirably positioned against the tissue region to be imaged along contact edge 22, the displacing fluid may be pumped at positive pressure through fluid delivery lumen 18 until the fluid fills open area 26 completely and displaces any fluid 28 from within open area 26. The displacing fluid flow may be laminarized to improve its clearing effect and to help prevent blood from re-entering the imaging hood 12. Alternatively, fluid flow may be started before the deployment takes place. The displacing fluid, also described herein as imaging fluid, may comprise any biocompatible fluid, e.g.,

saline, water, plasma, etc., which is sufficiently transparent to allow for relatively undistorted visualization through the fluid. Alternatively or additionally, any number of therapeutic drugs may be suspended within the fluid or may comprise the fluid itself which is pumped into open area 26 and which is subsequently passed into and through the heart and the patient body.

As seen in the example of FIGS. 2A and 2B, deployment catheter 16 may be manipulated to position deployed imaging hood 12 against or near the underlying tissue region of interest to be imaged, in this example a portion of annulus A of mitral valve MV within the left atrial chamber. As the surrounding blood 30 flows around imaging hood 12 and within open area 26 defined within imaging hood 12, as seen in FIG. 2A, the underlying annulus A is obstructed by the opaque blood 30 and is difficult to view through the imaging lumen 20. The translucent fluid 28, such as saline, may then be pumped through fluid delivery lumen 18, intermittently or continuously, until the blood 30 is at least partially, and preferably completely, displaced from within open area 26 by fluid 28, as shown in FIG. 2B.

Although contact edge 22 need not directly contact the underlying tissue, it is at least preferably brought into close proximity to the tissue such that the flow of clear fluid 28 from open area 26 may be maintained to inhibit significant back-flow of blood 30 back into open area 26. Contact edge 22 may also be made of a soft elastomeric material such as certain soft grades of silicone or polyurethane, as typically known, to help contact edge 22 conform to an uneven or rough underlying anatomical tissue surface. Once the blood 30 has been displaced from imaging hood 12, an image may then be viewed of the underlying tissue through the clear fluid 30. This image may then be recorded or available for real-time viewing for performing a therapeutic procedure. The positive flow of fluid 28 may be maintained continuously to provide for clear viewing of the underlying tissue. Alternatively, the fluid 28 may be pumped temporarily or sporadically only until a clear view of the tissue is available to be imaged and recorded, at which point the fluid flow 28 may cease and blood 30 may be allowed to seep or flow back into imaging hood 12. This process may be repeated a number of times at the same tissue region or at multiple tissue regions.

In desirably positioning the assembly at various regions within the patient body, a number of articulation and manipulation controls may be utilized. For example, as shown in the articulatable imaging assembly 40 in FIG. 3A, one or more push-pull wires 42 may be routed through deployment catheter 16 for steering the distal end portion of the device in various directions 46 to desirably position the imaging hood 12 adjacent to a region of tissue to be visualized. Depending upon the positioning and the number of push-pull wires 42 utilized, deployment catheter 16 and imaging hood 12 may be articulated into any number of configurations 44. The push-pull wire or wires 42 may be articulated via their proximal ends from outside the patient body manually utilizing one or more controls. Alternatively, deployment catheter 16 may be articulated by computer control, as further described below.

Additionally or alternatively, an articulatable delivery catheter 48, which may be articulated via one or more push-pull wires and having an imaging lumen and one or more working lumens, may be delivered through the deployment catheter 16 and into imaging hood 12. With a distal portion of articulatable delivery catheter 48 within imaging hood 12, the clear displacing fluid may be pumped through delivery catheter 48 or deployment catheter 16 to clear the field within imaging hood 12. As shown in FIG. 3B, the articulatable delivery catheter 48 may be articulated within the imaging

hood to obtain a better image of tissue adjacent to the imaging hood 12. Moreover, articulatable delivery catheter 48 may be articulated to direct an instrument or tool passed through the catheter 48, as described in detail below, to specific areas of tissue imaged through imaging hood 12 without having to reposition deployment catheter 16 and re-clear the imaging field within hood 12.

Alternatively, rather than passing an articulatable delivery catheter 48 through the deployment catheter 16, a distal portion of the deployment catheter 16 itself may comprise a distal end 49 which is articulatable within imaging hood 12, as shown in FIG. 3C. Directed imaging, instrument delivery, etc., may be accomplished directly through one or more lumens within deployment catheter 16 to specific regions of the underlying tissue imaged within imaging hood 12.

Visualization within the imaging hood 12 may be accomplished through an imaging lumen 20 defined through deployment catheter 16, as described above. In such a configuration, visualization is available in a straight-line manner, i.e., images are generated from the field distally along a longitudinal axis defined by the deployment catheter 16. Alternatively or additionally, an articulatable imaging assembly having a pivotable support member 50 may be connected to, mounted to, or otherwise passed through deployment catheter 16 to provide for visualization off-axis relative to the longitudinal axis defined by deployment catheter 16, as shown in FIG. 4A. Support member 50 may have an imaging element 52, e.g., a CCD or CMOS imager or optical fiber, attached at its distal end with its proximal end connected to deployment catheter 16 via a pivoting connection 54.

If one or more optical fibers are utilized for imaging, the optical fibers 58 may be passed through deployment catheter 16, as shown in the cross-section of FIG. 4B, and routed through the support member 50. The use of optical fibers 58 may provide for increased diameter sizes of the one or several lumens 56 through deployment catheter 16 for the passage of diagnostic and/or therapeutic tools therethrough. Alternatively, electronic chips, such as a charge coupled device (CCD) or a CMOS imager, which are typically known, may be utilized in place of the optical fibers 58, in which case the electronic imager may be positioned in the distal portion of the deployment catheter 16 with electric wires being routed proximally through the deployment catheter 16. Alternatively, the electronic imagers may be wirelessly coupled to a receiver for the wireless transmission of images. Additional optical fibers or light emitting diodes (LEDs) can be used to provide lighting for the image or operative theater, as described below in further detail. Support member 50 may be pivoted via connection 54 such that the member 50 can be positioned in a low-profile configuration within channel or groove 60 defined in a distal portion of catheter 16, as shown in the cross-section of FIG. 4C. During intravascular delivery of deployment catheter 16 through the patient body, support member 50 can be positioned within channel or groove 60 with imaging hood 12 also in its low-profile configuration. During visualization, imaging hood 12 may be expanded into its deployed configuration and support member 50 may be deployed into its off-axis configuration for imaging the tissue adjacent to hood 12, as in FIG. 4A. Other configurations for support member 50 for off-axis visualization may be utilized, as desired.

FIG. 5 shows an illustrative cross-sectional view of a heart H having tissue regions of interest being viewed via an imaging assembly 10. In this example, delivery catheter assembly 70 may be introduced percutaneously into the patient's vasculature and advanced through the superior vena cava SVC and into the right atrium RA. The delivery catheter or sheath

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72 may be articulated through the atrial septum AS and into the left atrium LA for viewing or treating the tissue, e.g., the annulus A, surrounding the mitral valve MV. As shown, deployment catheter 16 and imaging hood 12 may be advanced out of delivery catheter 72 and brought into contact or in proximity to the tissue region of interest. In other examples, delivery catheter assembly 70 may be advanced through the inferior vena cava IVC, if so desired. Moreover, other regions of the heart H, e.g., the right ventricle RV or left ventricle LV, may also be accessed and imaged or treated by imaging assembly 10.

In accessing regions of the heart H or other parts of the body, the delivery catheter or sheath 14 may comprise a conventional intra-vascular catheter or an endoluminal delivery device. Alternatively, robotically-controlled delivery catheters may also be optionally utilized with the imaging assembly described herein, in which case a computer-controller 74 may be used to control the articulation and positioning of the delivery catheter 14. An example of a robotically-controlled delivery catheter which may be utilized is described in further detail in US Pat. Pub. 2002/0087169 A1 to Brock et al. entitled "Flexible Instrument", which is incorporated herein by reference in its entirety. Other robotically-controlled delivery catheters manufactured by Hansen Medical, Inc. (Mountain View, Calif.) may also be utilized with the delivery catheter 14.

To facilitate stabilization of the deployment catheter 16 during a procedure, one or more inflatable balloons or anchors 76 may be positioned along the length of catheter 16, as shown in FIG. 6A. For example, when utilizing a transeptal approach across the atrial septum AS into the left atrium LA, the inflatable balloons 76 may be inflated from a low-profile into their expanded configuration to temporarily anchor or stabilize the catheter 16 position relative to the heart H. FIG. 6B shows a first balloon 78 inflated while FIG. 6C also shows a second balloon 80 inflated proximal to the first balloon 78. In such a configuration, the septal wall AS may be wedged or sandwiched between the balloons 78, 80 to temporarily stabilize the catheter 16 and imaging hood 12. A single balloon 78 or both balloons 78, 80 may be used. Other alternatives may utilize expandable mesh members, malecots, or any other temporary expandable structure. After a procedure has been accomplished, the balloon assembly 76 may be deflated or re-configured into a low-profile for removal of the deployment catheter 16.

To further stabilize a position of the imaging hood 12 relative to a tissue surface to be imaged, various anchoring mechanisms may be optionally employed for temporarily holding the imaging hood 12 against the tissue. Such anchoring mechanisms may be particularly useful for imaging tissue which is subject to movement, e.g., when imaging tissue within the chambers of a beating heart. A tool delivery catheter 82 having at least one instrument lumen and an optional visualization lumen may be delivered through deployment catheter 16 and into an expanded imaging hood 12. As the imaging hood 12 is brought into contact against a tissue surface T to be examined, anchoring mechanisms such as a helical tissue piercing device 84 may be passed through the tool delivery catheter 82, as shown in FIG. 7A, and into imaging hood 12.

The helical tissue engaging device 84 may be torqued from its proximal end outside the patient body to temporarily anchor itself into the underlying tissue surface T. Once embedded within the tissue T, the helical tissue engaging device 84 may be pulled proximally relative to deployment catheter 16 while the deployment catheter 16 and imaging hood 12 are pushed distally, as indicated by the arrows in FIG.

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7B, to gently force the contact edge or lip 22 of imaging hood against the tissue T. The positioning of the tissue engaging device 84 may be locked temporarily relative to the deployment catheter 16 to ensure secure positioning of the imaging hood 12 during a diagnostic or therapeutic procedure within the imaging hood 12. After a procedure, tissue engaging device 84 may be disengaged from the tissue by torquing its proximal end in the opposite direction to remove the anchor from the tissue T and the deployment catheter 16 may be repositioned to another region of tissue where the anchoring process may be repeated or removed from the patient body. The tissue engaging device 84 may also be constructed from other known tissue engaging devices such as vacuum-assisted engagement or grasper-assisted engagement tools, among others.

Although a helical anchor 84 is shown, this is intended to be illustrative and other types of temporary anchors may be utilized, e.g., hooked or barbed anchors, graspers, etc. Moreover, the tool delivery catheter 82 may be omitted entirely and the anchoring device may be delivered directly through a lumen defined through the deployment catheter 16.

In another variation where the tool delivery catheter 82 may be omitted entirely to temporarily anchor imaging hood 12, FIG. 7C shows an imaging hood 12 having one or more tubular support members 86, e.g., four support members 86 as shown, integrated with the imaging hood 12. The tubular support members 86 may define lumens therethrough each having helical tissue engaging devices 88 positioned within. When an expanded imaging hood 12 is to be temporarily anchored to the tissue, the helical tissue engaging devices 88 may be urged distally to extend from imaging hood 12 and each may be torqued from its proximal end to engage the underlying tissue T. Each of the helical tissue engaging devices 88 may be advanced through the length of deployment catheter 16 or they may be positioned within tubular support members 86 during the delivery and deployment of imaging hood 12. Once the procedure within imaging hood 12 is finished, each of the tissue engaging devices 88 may be disengaged from the tissue and the imaging hood 12 may be repositioned to another region of tissue or removed from the patient body.

An illustrative example is shown in FIG. 8A of a tissue imaging assembly connected to a fluid delivery system 90 and to an optional processor 98 and image recorder and/or viewer 100. The fluid delivery system 90 may generally comprise a pump 92 and an optional valve 94 for controlling the flow rate of the fluid into the system. A fluid reservoir 96, fluidly connected to pump 92, may hold the fluid to be pumped through imaging hood 12. An optional central processing unit or processor 98 may be in electrical communication with fluid delivery system 90 for controlling flow parameters such as the flow rate and/or velocity of the pumped fluid. The processor 98 may also be in electrical communication with an image recorder and/or viewer 100 for directly viewing the images of tissue received from within imaging hood 12. Image recorder and/or viewer 100 may also be used not only to record the image but also the location of the viewed tissue region, if so desired.

Optionally, processor 98 may also be utilized to coordinate the fluid flow and the image capture. For instance, processor 98 may be programmed to provide for fluid flow from reservoir 96 until the tissue area has been displaced of blood to obtain a clear image. Once the image has been determined to be sufficiently clear, either visually by a practitioner or by computer, an image of the tissue may be captured automatically by recorder 100 and pump 92 may be automatically stopped or slowed by processor 98 to cease the fluid flow into

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the patient. Other variations for fluid delivery and image capture are, of course, possible and the aforementioned configuration is intended only to be illustrative and not limiting.

FIG. 8B shows a further illustration of a hand-held variation of the fluid delivery and tissue manipulation system **110**. In this variation, system **110** may have a housing or handle assembly **112** which can be held or manipulated by the physician from outside the patient body. The fluid reservoir **114**, shown in this variation as a syringe, can be fluidly coupled to the handle assembly **112** and actuated via a pumping mechanism **116**, e.g., lead screw. Fluid reservoir **114** may be a simple reservoir separated from the handle assembly **112** and fluidly coupled to handle assembly **112** via one or more tubes. The fluid flow rate and other mechanisms may be metered by the electronic controller **118**.

Deployment of imaging hood **12** may be actuated by a hood deployment switch **120** located on the handle assembly **112** while dispensation of the fluid from reservoir **114** may be actuated by a fluid deployment switch **122**, which can be electrically coupled to the controller **118**. Controller **118** may also be electrically coupled to a wired or wireless antenna **124** optionally integrated with the handle assembly **112**, as shown in the figure. The wireless antenna **124** can be used to wirelessly transmit images captured from the imaging hood **12** to a receiver, e.g., via Bluetooth® wireless technology (Bluetooth SIG, Inc., Bellevue, Wash.), RF, etc., for viewing on a monitor **128** or for recording for later viewing.

Articulation control of the deployment catheter **16**, or a delivery catheter or sheath **14** through which the deployment catheter **16** may be delivered, may be accomplished by computer control, as described above, in which case an additional controller may be utilized with handle assembly **112**. In the case of manual articulation, handle assembly **112** may incorporate one or more articulation controls **126** for manual manipulation of the position of deployment catheter **16**. Handle assembly **112** may also define one or more instrument ports **130** through which a number of intravascular tools may be passed for tissue manipulation and treatment within imaging hood **12**, as described further below. Furthermore, in certain procedures, fluid or debris may be sucked into imaging hood **12** for evacuation from the patient body by optionally fluidly coupling a suction pump **132** to handle assembly **112** or directly to deployment catheter **16**.

As described above, fluid may be pumped continuously into imaging hood **12** to provide for clear viewing of the underlying tissue. Alternatively, fluid may be pumped temporarily or sporadically only until a clear view of the tissue is available to be imaged and recorded, at which point the fluid flow may cease and the blood may be allowed to seep or flow back into imaging hood **12**. FIGS. 9A to 9C illustrate an example of capturing several images of the tissue at multiple regions. Deployment catheter **16** may be desirably positioned and imaging hood **12** deployed and brought into position against a region of tissue to be imaged, in this example the tissue surrounding a mitral valve MV within the left atrium of a patient's heart. The imaging hood **12** may be optionally anchored to the tissue, as described above, and then cleared by pumping the imaging fluid into the hood **12**. Once sufficiently clear, the tissue may be visualized and the image captured by control electronics **118**. The first captured image **140** may be stored and/or transmitted wirelessly **124** to a monitor **128** for viewing by the physician, as shown in FIG. 9A.

The deployment catheter **16** may be then repositioned to an adjacent portion of mitral valve MV, as shown in FIG. 9B, where the process may be repeated to capture a second image **142** for viewing and/or recording. The deployment catheter

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**16** may again be repositioned to another region of tissue, as shown in FIG. 9C, where a third image **144** may be captured for viewing and/or recording. This procedure may be repeated as many times as necessary for capturing a comprehensive image of the tissue surrounding mitral valve MV, or any other tissue region. When the deployment catheter **16** and imaging hood **12** is repositioned from tissue region to tissue region, the pump may be stopped during positioning and blood or surrounding fluid may be allowed to enter within imaging hood **12** until the tissue is to be imaged, where the imaging hood **12** may be cleared, as above.

As mentioned above, when the imaging hood **12** is cleared by pumping the imaging fluid within for clearing the blood or other bodily fluid, the fluid may be pumped continuously to maintain the imaging fluid within the hood **12** at a positive pressure or it may be pumped under computer control for slowing or stopping the fluid flow into the hood **12** upon detection of various parameters or until a clear image of the underlying tissue is obtained. The control electronics **118** may also be programmed to coordinate the fluid flow into the imaging hood **12** with various physical parameters to maintain a clear image within imaging hood **12**.

One example is shown in FIG. 10A which shows a chart **150** illustrating how fluid pressure within the imaging hood **12** may be coordinated with the surrounding blood pressure. Chart **150** shows the cyclical blood pressure **156** alternating between diastolic pressure **152** and systolic pressure **154** over time T due to the beating motion of the patient heart. The fluid pressure of the imaging fluid, indicated by plot **160**, within imaging hood **12** may be automatically timed to correspond to the blood pressure changes **160** such that an increased pressure is maintained within imaging hood **12** which is consistently above the blood pressure **156** by a slight increase  $\Delta P$ , as illustrated by the pressure difference at the peak systolic pressure **158**. This pressure difference,  $\Delta P$ , may be maintained within imaging hood **12** over the pressure variance of the surrounding blood pressure to maintain a positive imaging fluid pressure within imaging hood **12** to maintain a clear view of the underlying tissue. One benefit of maintaining a constant  $\Delta P$  is a constant flow and maintenance of a clear field.

FIG. 10B shows a chart **162** illustrating another variation for maintaining a clear view of the underlying tissue where one or more sensors within the imaging hood **12**, as described in further detail below, may be configured to sense pressure changes within the imaging hood **12** and to correspondingly increase the imaging fluid pressure within imaging hood **12**. This may result in a time delay,  $\Delta T$ , as illustrated by the shifted fluid pressure **160** relative to the cycling blood pressure **156**, although the time delays  $\Delta T$  may be negligible in maintaining the clear image of the underlying tissue. Predictive software algorithms can also be used to substantially eliminate this time delay by predicting when the next pressure wave peak will arrive and by increasing the pressure ahead of the pressure wave's arrival by an amount of time equal to the aforementioned time delay to essentially cancel the time delay out.

The variations in fluid pressure within imaging hood **12** may be accomplished in part due to the nature of imaging hood **12**. An inflatable balloon, which is conventionally utilized for imaging tissue, may be affected by the surrounding blood pressure changes. On the other hand, an imaging hood **12** retains a constant volume therewithin and is structurally unaffected by the surrounding blood pressure changes, thus allowing for pressure increases therewithin. The material that hood **12** is made from may also contribute to the manner in which the pressure is modulated within this hood **12**. A stiffer

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hood material, such as high durometer polyurethane or Nylon, may facilitate the maintaining of an open hood when deployed. On the other hand, a relatively lower durometer or softer material, such as a low durometer PVC or polyurethane, may collapse from the surrounding fluid pressure and may not adequately maintain a deployed or expanded hood.

Turning now to the imaging hood, other variations of the tissue imaging assembly may be utilized, as shown in FIG. 11A, which shows another variation comprising an additional imaging balloon 172 within an imaging hood 174. In this variation, an expandable balloon 172 having a translucent skin may be positioned within imaging hood 174. Balloon 172 may be made from any distensible biocompatible material having sufficient translucent properties which allow for visualization therethrough. Once the imaging hood 174 has been deployed against the tissue region of interest, balloon 172 may be filled with a fluid, such as saline, or less preferably a gas, until balloon 172 has been expanded until the blood has been sufficiently displaced. The balloon 172 may thus be expanded proximal to or into contact against the tissue region to be viewed. The balloon 172 can also be filled with contrast media to allow it to be viewed on fluoroscopy to aid in its positioning. The imager, e.g., fiber optic, positioned within deployment catheter 170 may then be utilized to view the tissue region through the balloon 172 and any additional fluid which may be pumped into imaging hood 174 via one or more optional fluid ports 176, which may be positioned proximally of balloon 172 along a portion of deployment catheter 170. Alternatively, balloon 172 may define one or more holes over its surface which allow for seepage or passage of the fluid contained therein to escape and displace the blood from within imaging hood 174.

FIG. 11B shows another alternative in which balloon 180 may be utilized alone. Balloon 180, attached to deployment catheter 178, may be filled with fluid, such as saline or contrast media, and is preferably allowed to come into direct contact with the tissue region to be imaged.

FIG. 12A shows another alternative in which deployment catheter 16 incorporates imaging hood 12, as above, and includes an additional flexible membrane 182 within imaging hood 12. Flexible membrane 182 may be attached at a distal end of catheter 16 and optionally at contact edge 22. Imaging hood 12 may be utilized, as above, and membrane 182 may be deployed from catheter 16 in vivo or prior to placing catheter 16 within a patient to reduce the volume within imaging hood 12. The volume may be reduced or minimized to reduce the amount of fluid dispensed for visualization or simply reduced depending upon the area of tissue to be visualized.

FIGS. 12B and 12C show yet another alternative in which imaging hood 186 may be withdrawn proximally within deployment catheter 184 or deployed distally from catheter 186, as shown, to vary the volume of imaging hood 186 and thus the volume of dispensed fluid. Imaging hood 186 may be seen in FIG. 12B as being partially deployed from, e.g., a circumferentially defined lumen within catheter 184, such as annular lumen 188. The underlying tissue may be visualized with imaging hood 186 only partially deployed. Alternatively, imaging hood 186' may be fully deployed, as shown in FIG. 12C, by urging hood 186' distally out from annular lumen 188. In this expanded configuration, the area of tissue to be visualized may be increased as hood 186' is expanded circumferentially.

FIGS. 13A and 13B show perspective and cross-sectional side views, respectively, of yet another variation of imaging assembly which may utilize a fluid suction system for minimizing the amount of fluid injected into the patient's heart or other body lumen during tissue visualization. Deployment

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catheter 190 in this variation may define an inner tubular member 196 which may be integrated with deployment catheter 190 or independently translatable. Fluid delivery lumen 198 defined through member 196 may be fluidly connected to imaging hood 192, which may also define one or more open channels 194 over its contact lip region. Fluid pumped through fluid delivery lumen 198 may thus fill open area 202 to displace any blood or other fluids or objects therewithin. As the clear fluid is forced out of open area 202, it may be sucked or drawn immediately through one or more channels 194 and back into deployment catheter 190. Tubular member 196 may also define one or more additional working channels 200 for the passage of any tools or visualization devices.

In deploying the imaging hood in the examples described herein, the imaging hood may take on any number of configurations when positioned or configured for a low-profile delivery within the delivery catheter, as shown in the examples of FIGS. 14A to 14D. These examples are intended to be illustrative and are not intended to be limiting in scope. FIG. 14A shows one example in which imaging hood 212 may be compressed within catheter 210 by folding hood 212 along a plurality of pleats. Hood 212 may also comprise scaffolding or frame 214 made of a super-elastic or shape memory material or alloy, e.g., Nitinol, Elgiloy, shape memory polymers, electroactive polymers, or a spring stainless steel. The shape memory material may act to expand or deploy imaging hood 212 into its expanded configuration when urged in the direction of the arrow from the constraints of catheter 210.

FIG. 14B shows another example in which imaging hood 216 may be expanded or deployed from catheter 210 from a folded and overlapping configuration. Frame or scaffolding 214 may also be utilized in this example. FIG. 14C shows yet another example in which imaging hood 218 may be rolled, inverted, or everted upon itself for deployment. In yet another example, FIG. 14D shows a configuration in which imaging hood 220 may be fabricated from an extremely compliant material which allows for hood 220 to be simply compressed into a low-profile shape. From this low-profile compressed shape, simply releasing hood 220 may allow for it to expand into its deployed configuration, especially if a scaffold or frame of a shape memory or superelastic material, e.g., Nitinol, is utilized in its construction.

Another variation for expanding the imaging hood is shown in FIGS. 15A and 15B which illustrates an helically expanding frame or support 230. In its constrained low-profile configuration, shown in FIG. 15A, helical frame 230 may be integrated with the imaging hood 12 membrane. When free to expand, as shown in FIG. 15B, helical frame 230 may expand into a conical or tapered shape. Helical frame 230 may alternatively be made out of heat-activated Nitinol to allow it to expand upon application of a current.

FIGS. 16A and 16B show yet another variation in which imaging hood 12 may comprise one or more hood support members 232 integrated with the hood membrane. These longitudinally attached support members 232 may be pivotably attached at their proximal ends to deployment catheter 16. One or more pullwires 234 may be routed through the length of deployment catheter 16 and extend through one or more openings 238 defined in deployment catheter 16 proximally to imaging hood 12 into attachment with a corresponding support member 232 at a pullwire attachment point 236. The support members 232 may be fabricated from a plastic or metal, such as stainless steel. Alternatively, the support members 232 may be made from a superelastic or shape memory alloy, such as Nitinol, which may self-expand into its deployed configuration without the use or need of pullwires.

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A heat-activated Nitinol may also be used which expands upon the application of thermal energy or electrical energy. In another alternative, support members **232** may also be constructed as inflatable lumens utilizing, e.g., PET balloons. From its low-profile delivery configuration shown in FIG. **16A**, the one or more pullwires **234** may be tensioned from their proximal ends outside the patient body to pull a corresponding support member **232** into a deployed configuration, as shown in FIG. **16B**, to expand imaging hood **12**. To reconfigure imaging hood **12** back into its low profile, deployment catheter **16** may be pulled proximally into a constraining catheter or the pullwires **234** may be simply pushed distally to collapse imaging hood **12**.

FIGS. **17A** and **17B** show yet another variation of imaging hood **240** having at least two or more longitudinally positioned support members **242** supporting the imaging hood membrane. The support members **242** each have cross-support members **244** which extend diagonally between and are pivotably attached to the support members **242**. Each of the cross-support members **244** may be pivotably attached to one another where they intersect between the support members **242**. A jack or screw member **246** may be coupled to each cross-support member **244** at this intersection point and a torquing member, such as a torqueable wire **248**, may be coupled to each jack or screw member **246** and extend proximally through deployment catheter **16** to outside the patient body. From outside the patient body, the torqueable wires **248** may be torqued to turn the jack or screw member **246** which in turn urges the cross-support members **244** to angle relative to one another and thereby urge the support members **242** away from one another. Thus, the imaging hood **240** may be transitioned from its low-profile, shown in FIG. **17A**, to its expanded profile, shown in FIG. **17B**, and back into its low-profile by torquing wires **248**.

FIGS. **18A** and **18B** show yet another variation on the imaging hood and its deployment. As shown, a distal portion of deployment catheter **16** may have several pivoting members **250**, e.g., two to four sections, which form a tubular shape in its low profile configuration, as shown in FIG. **18A**. When pivoted radially about deployment catheter **16**, pivoting members **250** may open into a deployed configuration having distensible or expanding membranes **252** extending over the gaps in-between the pivoting members **250**, as shown in FIG. **18B**. The distensible membrane **252** may be attached to the pivoting members **250** through various methods, e.g., adhesives, such that when the pivoting members **250** are fully extended into a conical shape, the pivoting members **250** and membrane **252** form a conical shape for use as an imaging hood. The distensible membrane **252** may be made out of a porous material such as a mesh or PTFE or out of a translucent or transparent polymer such as polyurethane, PVC, Nylon, etc.

FIGS. **19A** and **19B** show yet another variation where the distal portion of deployment catheter **16** may be fabricated from a flexible metallic or polymeric material to form a radially expanding hood **254**. A plurality of slots **256** may be formed in a uniform pattern over the distal portion of deployment catheter **16**, as shown in FIG. **19A**. The slots **256** may be formed in a pattern such that when the distal portion is urged radially open, utilizing any of the methods described above, a radially expanded and conically-shaped hood **254** may be formed by each of the slots **256** expanding into an opening, as shown in FIG. **19B**. A distensible membrane **258** may overlie the exterior surface or the interior surface of the hood **254** to form a fluid-impermeable hood **254** such that the hood **254** may be utilized as an imaging hood. Alternatively, the distensible membrane **258** may alternatively be formed in each

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opening **258** to form the fluid-impermeable hood **254**. Once the imaging procedure has been completed, hood **254** may be retracted into its low-profile configuration.

Yet another configuration for the imaging hood may be seen in FIGS. **20A** and **20B** where the imaging hood may be formed from a plurality of overlapping hood members **260** which overlie one another in an overlapping pattern. When expanded, each of the hood members **260** may extend radially outward relative to deployment catheter **16** to form a conically-shaped imaging hood, as shown in FIG. **20B**. Adjacent hood members **260** may overlap one another along an overlapping interface **262** to form a fluid-retaining surface within the imaging hood. Moreover, the hood members **260** may be made from any number of biocompatible materials, e.g., Nitinol, stainless steel, polymers, etc., which are sufficiently strong to optionally retract surrounding tissue from the tissue region of interest.

Although it is generally desirable to have an imaging hood contact against a tissue surface in a normal orientation, the imaging hood may be alternatively configured to contact the tissue surface at an acute angle. An imaging hood configured for such contact against tissue may also be especially suitable for contact against tissue surfaces having an unpredictable or uneven anatomical geography. For instance, as shown in the variation of FIG. **21A**, deployment catheter **270** may have an imaging hood **272** that is configured to be especially compliant. In this variation, imaging hood **272** may be comprised of one or more sections **274** that are configured to fold or collapse, e.g., by utilizing a pleated surface. Thus, as shown in FIG. **21B**, when imaging hood **272** is contacted against uneven tissue surface **T**, sections **274** are able to conform closely against the tissue. These sections **274** may be individually collapsible by utilizing an accordion style construction to allow conformation, e.g., to the trabeculae in the heart or the uneven anatomy that may be found inside the various body lumens.

In yet another alternative, FIG. **22A** shows another variation in which an imaging hood **282** is attached to deployment catheter **280**. The contact lip or edge **284** may comprise one or more electrical contacts **286** positioned circumferentially around contact edge **284**. The electrical contacts **286** may be configured to contact the tissue and indicate affirmatively whether tissue contact was achieved, e.g., by measuring the differential impedance between blood and tissue. Alternatively, a processor, e.g., processor **98**, in electrical communication with contacts **286** may be configured to determine what type of tissue is in contact with electrical contacts **286**. In yet another alternative, the processor **98** may be configured to measure any electrical activity that may be occurring in the underlying tissue, e.g., accessory pathways, for the purposes of electrically mapping the cardiac tissue and subsequently treating, as described below, any arrhythmias which may be detected.

Another variation for ensuring contact between imaging hood **282** and the underlying tissue may be seen in FIG. **22B**. This variation may have an inflatable contact edge **288** around the circumference of imaging hood **282**. The inflatable contact edge **288** may be inflated with a fluid or gas through inflation lumen **289** when the imaging hood **282** is to be placed against a tissue surface having an uneven or varied anatomy. The inflated circumferential surface **288** may provide for continuous contact over the hood edge by conforming against the tissue surface and facilitating imaging fluid retention within hood **282**.

Aside from the imaging hood, various instrumentation may be utilized with the imaging and manipulation system. For instance, after the field within imaging hood **12** has been



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cleared of the opaque blood and the underlying tissue is visualized through the clear fluid, blood may seep back into the imaging hood 12 and obstruct the view. One method for automatically maintaining a clear imaging field may utilize a transducer, e.g., an ultrasonic transducer 290, positioned at the distal end of deployment catheter within the imaging hood 12, as shown in FIG. 23. The transducer 290 may send an energy pulse 292 into the imaging hood 12 and wait to detect back-scattered energy 294 reflected from debris or blood within the imaging hood 12. If back-scattered energy is detected, the pump may be actuated automatically to dispense more fluid into the imaging hood until the debris or blood is no longer detected.

Alternatively, one or more sensors 300 may be positioned on the imaging hood 12 itself, as shown in FIG. 24A, to detect a number of different parameters. For example, sensors 300 may be configured to detect for the presence of oxygen in the surrounding blood, blood and/or imaging fluid pressure, color of the fluid within the imaging hood, etc. Fluid color may be particularly useful in detecting the presence of blood within the imaging hood 12 by utilizing a reflective type sensor to detect back reflection from blood. Any reflected light from blood which may be present within imaging hood 12 may be optically or electrically transmitted through deployment catheter 16 and to a red colored filter within control electronics 118. Any red color which may be detected may indicate the presence of blood and trigger a signal to the physician or automatically actuate the pump to dispense more fluid into the imaging hood 12 to clear the blood.

Alternative methods for detecting the presence of blood within the hood 12 may include detecting transmitted light through the imaging fluid within imaging hood 12. If a source of white light, e.g., utilizing LEDs or optical fibers, is illuminated inside imaging hood 12, the presence of blood may cause the color red to be filtered through this fluid. The degree or intensity of the red color detected may correspond to the amount of blood present within imaging hood 12. A red color sensor can simply comprise, in one variation, a phototransistor with a red transmitting filter over it which can establish how much red light is detected, which in turn can indicate the presence of blood within imaging hood 12. Once blood is detected, the system may pump more clearing fluid through and enable closed loop feedback control of the clearing fluid pressure and flow level.

Any number of sensors may be positioned along the exterior 302 of imaging hood 12 or within the interior 304 of imaging hood 12 to detect parameters not only exteriorly to imaging hood 12 but also within imaging hood 12. Such a configuration, as shown in FIG. 24B, may be particularly useful for automatically maintaining a clear imaging field based upon physical parameters such as blood pressure, as described above for FIGS. 10A and 10B.

Aside from sensors, one or more light emitting diodes (LEDs) may be utilized to provide lighting within the imaging hood 12. Although illumination may be provided by optical fibers routed through deployment catheter 16, the use of LEDs over the imaging hood 12 may eliminate the need for additional optical fibers for providing illumination. The electrical wires connected to the one or more LEDs may be routed through or over the hood 12 and along an exterior surface or extruded within deployment catheter 16. One or more LEDs may be positioned in a circumferential pattern 306 around imaging hood 12, as shown in FIG. 25A, or in a linear longitudinal pattern 308 along imaging hood 12, as shown in FIG. 25B. Other patterns, such as a helical or spiral pattern, may also be utilized. Alternatively, LEDs may be positioned along a support member forming part of imaging hood 12.

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In another alternative for illumination within imaging hood 12, a separate illumination tool 310 may be utilized, as shown in FIG. 26A. An example of such a tool may comprise a flexible intravascular delivery member 312 having a carrier member 314 pivotably connected 316 to a distal end of delivery member 312. One or more LEDs 318 may be mounted along carrier member 314. In use, delivery member 312 may be advanced through deployment catheter 16 until carrier member 314 is positioned within imaging hood 12. Once within imaging hood 12, carrier member 314 may be pivoted in any number of directions to facilitate or optimize the illumination within the imaging hood 12, as shown in FIG. 26B.

In utilizing LEDs for illumination, whether positioned along imaging hood 12 or along a separate instrument, the LEDs may comprise a single LED color, e.g., white light. Alternatively, LEDs of other colors, e.g., red, blue, yellow, etc., may be utilized exclusively or in combination with white LEDs to provide for varied illumination of the tissue or fluids being imaged. Alternatively, sources of infrared or ultraviolet light may be employed to enable imaging beneath the tissue surface or cause fluorescence of tissue for use in system guidance, diagnosis, or therapy.

Aside from providing a visualization platform, the imaging assembly may also be utilized to provide a therapeutic platform for treating tissue being visualized. As shown in FIG. 27, deployment catheter 320 may have imaging hood 322, as described above, and fluid delivery lumen 324 and imaging lumen 326. In this variation, a therapeutic tool such as needle 328 may be delivered through fluid delivery lumen 324 or in another working lumen and advanced through open area 332 for treating the tissue which is visualized. In this instance, needle 328 may define one or several ports 330 for delivering drugs therethrough. Thus, once the appropriate region of tissue has been imaged and located, needle 328 may be advanced and pierced into the underlying tissue where a therapeutic agent may be delivered through ports 330. Alternatively, needle 328 may be in electrical communication with a power source 334, e.g., radio-frequency, microwave, etc., for ablating the underlying tissue area of interest.

FIG. 28 shows another alternative in which deployment catheter 340 may have imaging hood 342 attached thereto, as above, but with a therapeutic tool 344 in the configuration of a helical tissue piercing device 344. Also shown and described above in FIGS. 7A and 7B for use in stabilizing the imaging hood relative to the underlying tissue, the helical tissue piercing device 344 may also be utilized to manipulate the tissue for a variety of therapeutic procedures. The helical portion 346 may also define one or several ports for delivery of therapeutic agents therethrough.

In yet another alternative, FIG. 29 shows a deployment catheter 350 having an expandable imaging balloon 352 filled with, e.g., saline 356. A therapeutic tool 344, as above, may be translatable relative to balloon 352. To prevent the piercing portion 346 of the tool from tearing balloon 352, a stop 354 may be formed on balloon 352 to prevent the proximal passage of portion 346 past stop 354.

Alternative configurations for tools which may be delivered through deployment catheter 16 for use in tissue manipulation within imaging hood 12 are shown in FIGS. 30A and 30B. FIG. 30A shows one variation of an angled instrument 360, such as a tissue grasper, which may be configured to have an elongate shaft for intravascular delivery through deployment catheter 16 with a distal end which may be angled relative to its elongate shaft upon deployment into imaging hood 12. The elongate shaft may be configured to angle itself automatically, e.g., by the elongate shaft being made at least partially from a shape memory alloy, or upon actuation, e.g.,



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by tensioning a pullwire. FIG. 30B shows another configuration for an instrument 362 being configured to reconfigure its distal portion into an off-axis configuration within imaging hood 12. In either case, the instruments 360, 362 may be reconfigured into a low-profile shape upon withdrawing them proximally back into deployment catheter 16.

Other instruments or tools which may be utilized with the imaging system is shown in the side and end views of FIGS. 31A to 31C. FIG. 31A shows a probe 370 having a distal end effector 372, which may be reconfigured from a low-profile shape to a curved profile. The end effector 372 may be configured as an ablation probe utilizing radio-frequency energy, microwave energy, ultrasound energy, laser energy or even cryo-ablation. Alternatively, the end effector 372 may have several electrodes upon it for detecting or mapping electrical signals transmitted through the underlying tissue.

In the case of an end effector 372 utilized for ablation of the underlying tissue, an additional temperature sensor such as a thermocouple or thermistor 374 positioned upon an elongate member 376 may be advanced into the imaging hood 12 adjacent to the distal end effector 372 for contacting and monitoring a temperature of the ablated tissue. FIG. 31B shows an example in the end view of one configuration for the distal end effector 372 which may be simply angled into a perpendicular configuration for contacting the tissue. FIG. 31C shows another example where the end effector may be reconfigured into a curved end effector 378 for increased tissue contact.

FIGS. 32A and 32B show another variation of an ablation tool utilized with an imaging hood 12 having an enclosed bottom portion. In this variation, an ablation probe, such as a cryo-ablation probe 380 having a distal end effector 382, may be positioned through the imaging hood 12 such that the end effector 382 is placed distally of a transparent membrane or enclosure 384, as shown in the end view of FIG. 32B. The shaft of probe 380 may pass through an opening 386 defined through the membrane 384. In use, the clear fluid may be pumped into imaging hood 12, as described above, and the distal end effector 382 may be placed against a tissue region to be ablated with the imaging hood 12 and the membrane 384 positioned atop or adjacent to the ablated tissue. In the case of cryo-ablation, the imaging fluid may be warmed prior to dispensing into the imaging hood 12 such that the tissue contacted by the membrane 384 may be warmed during the cryo-ablation procedure. In the case of thermal ablation, e.g., utilizing radio-frequency energy, the fluid dispensed into the imaging hood 12 may be cooled such that the tissue contacted by the membrane 384 and adjacent to the ablation probe during the ablation procedure is likewise cooled.

In either example described above, the imaging fluid may be varied in its temperature to facilitate various procedures to be performed upon the tissue. In other cases, the imaging fluid itself may be altered to facilitate various procedures. For instance as shown in FIG. 33A, a deployment catheter 16 and imaging hood 12 may be advanced within a hollow body organ, such as a bladder filled with urine 394, towards a lesion or tumor 392 on the bladder wall. The imaging hood 12 may be placed entirely over the lesion 392, or over a portion of the lesion. Once secured against the tissue wall 390, a cryo-fluid, i.e., a fluid which has been cooled to below freezing temperatures of, e.g., water or blood, may be pumped into the imaging hood 12 to cryo-ablate the lesion 390, as shown in FIG. 33B while avoiding the creation of ice on the instrument or surface of tissue.

As the cryo-fluid leaks out of the imaging hood 12 and into the organ, the fluid may be warmed naturally by the patient body and ultimately removed. The cryo-fluid may be a col-

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orless and translucent fluid which enables visualization there-through of the underlying tissue. An example of such a fluid is Fluorinert™ (3M, St. Paul, Minn.), which is a colorless and odorless perfluorinated liquid. The use of a liquid such as Fluorinert™ enables the cryo-ablation procedure without the formation of ice within or outside of the imaging hood 12. Alternatively, rather than utilizing cryo-ablation, hyperthermic treatments may also be effected by heating the Fluorinert™ liquid to elevated temperatures for ablating the lesion 392 within the imaging hood 12. Moreover, Fluorinert™ may be utilized in various other parts of the body, such as within the heart.

FIG. 34A shows another variation of an instrument which may be utilized with the imaging system. In this variation, a laser ring generator 400 may be passed through the deployment catheter 16 and partially into imaging hood 12. A laser ring generator 400 is typically used to create a circular ring of laser energy 402 for generating a conduction block around the pulmonary veins typically in the treatment of atrial fibrillation. The circular ring of laser energy 402 may be generated such that a diameter of the ring 402 is contained within a diameter of the imaging hood 12 to allow for tissue ablation directly upon tissue being imaged. Signals which cause atrial fibrillation typically come from the entry area of the pulmonary veins into the left atrium and treatments may sometimes include delivering ablation energy to the ostia of the pulmonary veins within the atrium. The ablated areas of the tissue may produce a circular scar which blocks the impulses for atrial fibrillation.

When using the laser energy to ablate the tissue of the heart, it may be generally desirable to maintain the integrity and health of the tissue overlying the surface while ablating the underlying tissue. This may be accomplished, for example, by cooling the imaging fluid to a temperature below the body temperature of the patient but which is above the freezing point of blood (e.g., 2° C. to 35° C.). The cooled imaging fluid may thus maintain the surface tissue at the cooled fluid temperature while the deeper underlying tissue remains at the patient body temperature. When the laser energy (or other types of energy such as radio frequency energy, microwave energy, ultrasound energy, etc.) irradiates the tissue, both the cooled tissue surface as well as the deeper underlying tissue will rise in temperature uniformly. The deeper underlying tissue, which was maintained at the body temperature, will increase to temperatures which are sufficiently high to destroy the underlying tissue. Meanwhile, the temperature of the cooled surface tissue will also rise but only to temperatures that are near body temperature or slightly above.

Accordingly, as shown in FIG. 34B, one example for treatment may include passing deployment catheter 16 across the atrial septum AS and into the left atrium LA of the patient's heart H. Other methods of accessing the left atrium LA may also be utilized. The imaging hood 12 and laser ring generator 400 may be positioned adjacent to or over one or more of the ostium OT of the pulmonary veins PV and the laser generator 400 may ablate the tissue around the ostium OT with the circular ring of laser energy 402 to create a conduction block. Once one or more of the tissue around the ostium OT have been ablated, the imaging hood 12 may be reconfigured into a low profile for removal from the patient heart H.

One of the difficulties in treating tissue in or around the ostium OT is the dynamic fluid flow of blood through the ostium OT. The dynamic forces make cannulation or entry of the ostium OT difficult. Thus, another variation on instruments or tools utilizable with the imaging system is an extendible cannula 410 having a cannula lumen 412 defined therethrough, as shown in FIG. 35A. The extendible cannula

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410 may generally comprise an elongate tubular member which may be positioned within the deployment catheter 16 during delivery and then projected distally through the imaging hood 12 and optionally beyond, as shown in FIG. 35B.

In use, once the imaging hood 12 has been desirably positioned relative to the tissue, e.g., as shown in FIG. 35C outside the ostium OT of a pulmonary vein PV, the extendible cannula 410 may be projected distally from the deployment catheter 16 while optionally imaging the tissue through the imaging hood 12, as described above. The extendible cannula 410 may be projected distally until its distal end is extended at least partially into the ostium OT. Once in the ostium OT, an instrument or energy ablation device may be extended through and out of the cannula lumen 412 for treatment within the ostium OT. Upon completion of the procedure, the cannula 410 may be withdrawn proximally and removed from the patient body. The extendible cannula 410 may also include an inflatable occlusion balloon at or near its distal end to block the blood flow out of the PV to maintain a clear view of the tissue region. Alternatively, the extendible cannula 410 may define a lumen therethrough beyond the occlusion balloon to bypass at least a portion of the blood that normally exists the pulmonary vein PV by directing the blood through the cannula 410 to exit proximal of the imaging hood.

Yet another variation for tool or instrument use may be seen in the side and end views of FIGS. 36A and 36B. In this variation, imaging hood 12 may have one or more tubular support members 420 integrated with the hood 12. Each of the tubular support members 420 may define an access lumen 422 through which one or more instruments or tools may be delivered for treatment upon the underlying tissue. One particular example is shown and described above for FIG. 7C.

Various methods and instruments may be utilized for using or facilitating the use of the system. For instance, one method may include facilitating the initial delivery and placement of a device into the patient's heart. In initially guiding the imaging assembly within the heart chamber to, e.g., the mitral valve MV, a separate guiding probe 430 may be utilized, as shown in FIGS. 37A and 37B. Guiding probe 430 may, for example, comprise an optical fiber through which a light source 434 may be used to illuminate a distal tip portion 432. The tip portion 432 may be advanced into the heart through, e.g., the coronary sinus CS, until the tip is positioned adjacent to the mitral valve MV. The tip 432 may be illuminated, as shown in FIG. 37A, and imaging assembly 10 may then be guided towards the illuminated tip 432, which is visible from within the atrial chamber, towards mitral valve MV.

Aside from the devices and methods described above, the imaging system may be utilized to facilitate various other procedures. Turning now to FIGS. 38A and 38B, the imaging hood of the device in particular may be utilized. In this example, a collapsible membrane or disk-shaped member 440 may be temporarily secured around the contact edge or lip of imaging hood 12. During intravascular delivery, the imaging hood 12 and the attached member 440 may both be in a collapsed configuration to maintain a low profile for delivery. Upon deployment, both the imaging hood 12 and the member 440 may extend into their expanded configurations.

The disk-shaped member 440 may be comprised of a variety of materials depending upon the application. For instance, member 440 may be fabricated from a porous polymeric material infused with a drug eluting medicament 442 for implantation against a tissue surface for slow infusion of the medicament into the underlying tissue. Alternatively, the member 440 may be fabricated from a non-porous material, e.g., metal or polymer, for implantation and closure of a wound or over a cavity to prevent fluid leakage. In yet another

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alternative, the member 440 may be made from a distensible material which is secured to imaging hood 12 in an expanded condition. Once implanted or secured on a tissue surface or wound, the expanded member 440 may be released from imaging hood 12. Upon release, the expanded member 440 may shrink to a smaller size while approximating the attached underlying tissue, e.g., to close a wound or opening.

One method for securing the disk-shaped member 440 to a tissue surface may include a plurality of tissue anchors 444, e.g., barbs, hooks, projections, etc., which are attached to a surface of the member 440. Other methods of attachments may include adhesives, suturing, etc. In use, as shown in FIGS. 39A to 39C, the imaging hood 12 may be deployed in its expanded configuration with member 440 attached thereto with the plurality of tissue anchors 444 projecting distally. The tissue anchors 444 may be urged into a tissue region to be treated 446, as seen in FIG. 39A, until the anchors 444 are secured in the tissue and member 440 is positioned directly against the tissue, as shown in FIG. 39B. A pullwire may be actuated to release the member 440 from the imaging hood 12 and deployment catheter 16 may be withdrawn proximally to leave member 440 secured against the tissue 446.

Another variation for tissue manipulation and treatment may be seen in the variation of FIG. 40A, which illustrates an imaging hood 12 having a deployable anchor assembly 450 attached to the tissue contact edge 22. FIG. 40B illustrates the anchor assembly 450 detached from the imaging hood 12 for clarity. The anchor assembly 450 may be seen as having a plurality of discrete tissue anchors 456, e.g., barbs, hooks, projections, etc., each having a suture retaining end, e.g., an eyelet or opening 458 in a proximal end of the anchors 456. A suture member or wire 452 may be slidably connected to each anchor 456 through the openings 458 and through a cinching element 454, which may be configured to slide uni-directionally over the suture or wire 452 to approximate each of the anchors 456 towards one another. Each of the anchors 456 may be temporarily attached to the imaging hood 12 through a variety of methods. For instance, a pullwire or retaining wire may hold each of the anchors within a receiving ring around the circumference of the imaging hood 12. When the anchors 456 are released, the pullwire or retaining wire may be tensioned from its proximal end outside the patient body to thereby free the anchors 456 from the imaging hood 12.

One example for use of the anchor assembly 450 is shown in FIGS. 41A to 41D for closure of an opening or wound 460, e.g., patent foramen ovale (PFO). The deployment catheter 16 and imaging hood 12 may be delivered intravascularly into, e.g., a patient heart. As the imaging hood 12 is deployed into its expanded configuration, the imaging hood 12 may be positioned adjacent to the opening or wound 460, as shown in FIG. 41A. With the anchor assembly 450 positioned upon the expanded imaging hood 12, deployment catheter 16 may be directed to urge the contact edge of imaging hood 12 and anchor assembly 450 into the region surrounding the tissue opening 460, as shown in FIG. 41B. Once the anchor assembly 450 has been secured within the surrounding tissue, the anchors may be released from imaging hood 12 leaving the anchor assembly 450 and suture member 452 trailing from the anchors, as shown in FIG. 41C. The suture or wire member 452 may be tightened by pulling it proximally from outside the patient body to approximate the anchors of anchor assembly 450 towards one another in a purse-string manner to close the tissue opening 462, as shown in FIG. 41D. The cinching element 454 may also be pushed distally over the suture or wire member 452 to prevent the approximated anchor assembly 450 from loosening or widening.

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Another example for an alternative use is shown in FIG. 42, where the deployment catheter 16 and deployed imaging hood 12 may be positioned within a patient body for drawing blood 472 into deployment catheter 16. The drawn blood 472 may be pumped through a dialysis unit 470 located externally of the patient body for filtering the drawn blood 472 and the filtered blood may be reintroduced back into the patient.

Yet another variation is shown in FIGS. 43A and 43B, which show a variation of the deployment catheter 480 having a first deployable hood 482 and a second deployable hood 484 positioned distal to the first hood 482. The deployment catheter 480 may also have a side-viewing imaging element 486 positioned between the first and second hoods 482, 484 along the length of the deployment catheter 480. In use, such a device may be introduced through a lumen 488 of a vessel VS, where one or both hoods 482, 484 may be expanded to gently contact the surrounding walls of vessel VS. Once hoods 482, 484 have been expanded, the clear imaging fluid may be pumped in the space defined between the hoods 482, 484 to displace any blood and to create an imaging space 490, as shown in FIG. 43B. With the clear fluid in-between hoods 482, 484, the imaging element 486 may be used to view the surrounding tissue surface contained between hoods 482, 484. Other instruments or tools may be passed through deployment catheter 480 and through one or more openings defined along the catheter 480 for additionally performing therapeutic procedures upon the vessel wall.

Another variation of a deployment catheter 500 which may be used for imaging tissue to the side of the instrument may be seen in FIGS. 44A to 45B. FIGS. 44A and 44B show side and end views of deployment catheter 500 having a side-imaging balloon 502 in an un-inflated low-profile configuration. A side-imaging element 504 may be positioned within a distal portion of the catheter 500 where the balloon 502 is disposed. When balloon 502 is inflated, it may expand radially to contact the surrounding tissue, but where the imaging element 504 is located, a visualization field 506 may be created by the balloon 502, as shown in the side, top, and end views of FIGS. 45A to 45B, respectively. The visualization field 506 may simply be a cavity or channel which is defined within the inflated balloon 502 such that the visualization element 504 is provided an image of the area within field 506 which is clear and unobstructed by balloon 502.

In use, deployment catheter 500 may be advanced intravascularly through vessel lumen 488 towards a lesion or tumor 508 to be visualized and/or treated. Upon reaching the lesion 508, deployment catheter 500 may be positioned adjacently to the lesion 508 and balloon 502 may be inflated such that the lesion 508 is contained within the visualization field 506. Once balloon 502 is fully inflated and in contact against the vessel wall, clear fluid may be pumped into visualization field 506 through deployment catheter 500 to displace any blood or opaque fluids from the field 506, as shown in the side and end views of FIGS. 46A and 46B, respectively. The lesion 508 may then be visually inspected and treated by passing any number of instruments through deployment catheter 500 and into field 506.

In another example of an assembly for viewing tissue laterally relative to the catheter, FIGS. 47A and 47B show perspective views of elongate shaft 510 defining a lateral opening 514 along its side surface. Shaft 510 may define a lumen 512 through which a visualization device, such as an optical fiber viewing element, may be advanced through. An expandable membrane 516 may be positioned over lateral opening 514 such that upon expansion of membrane 516, the balloon may expand laterally, as shown in FIG. 47B. When inflated in a narrow body lumen, such as the coronary sinus, the balloon

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514 may push the shaft 510 laterally towards the lumen wall. As such, vision along the longitudinal axis of the shaft 510 may be unobstructed as the inflated balloon 514 is transparent. Such a variation can be used to cannulate body lumens and/or visualize the interior of the lumen as well.

FIG. 48 shows a perspective view of another variation of the tissue visualization catheter having an expandable balloon 522 disposed within the open area of hood 12. Balloon 522 may be comprised of a flexible and transparent material, for instance being comprised of the same material as hood 12. Moreover, multiple slit valves 524 may be defined over a distal surface of the balloon 522 where each slit valve 524 may be configured as a unidirectional valve which prevents or inhibits bodily fluids, such as blood, outside the balloon 522 from entering into the balloon interior. Each slit valve 524 defined over the balloon surface may serve as an exit point for an instrument, e.g., guidewire 526, delivered through the hood 12 for treating the underlying tissue while under direction visual guidance from imaging element 520, e.g., CMOS, CCD, or optical fiber, etc. The presence of multiple slit valves 524 may provide a variety of possible exit points for the guidewire 526. During cannulation procedures, such as coronary sinus cannulation, once the balloon is placed generally within the vicinity of the ostium, the guidewire 526 itself can be articulated within the inflated balloon 522 to pass through one of the slits 524 closest to the ostia such that the guidewire 526 may enter directly into a vessel of interest without having to reposition the entire catheter.

Another variation is illustrated in the perspective view of FIG. 49, which shows an expandable balloon 530 similarly having multiple unidirectional slit valves 524 defined over a distal surface of the balloon 530. In this example, hood 12 may be omitted to allow the balloon 530 to expand unconstrained by the hood 12. Similar to the previous variation, each slit valve 524 may inhibit or prevent bodily fluids, such as blood, from entering into the balloon 530 while providing a variety of exit points for guidewire 526. Additionally, rather than utilizing an imaging element positioned along the hood interior off-axis relative to a longitudinal axis of the hood 12, an imaging element 532 may be positioned within the balloon 530 at the distal end of catheter 16.

A pressure gauge may be optionally positioned within the balloons 522, 530 of FIGS. 48 and 49 to detect inflation pressure. With the ability to monitor inflation pressure, pressures can be increased to a level higher than the blood pressure of the heart chamber to allow an inflation fluid, such as saline, to escape through the one-way valves 524 to the exterior of the balloons. This feature can be useful when RF ablation through the balloon wall is performed or when small amount of saline is required to wet the exterior of the balloon during visualization.

Yet another variation is illustrated in the perspective view of FIG. 50, which shows a tissue visualization catheter having multiple individual elongated balloon members 540 inflated longitudinally within hood 12. Each elongated balloon 540 is transparent with its proximal end attached to the inner wall of hood 12. The balloons 540 may facilitate displacement of blood from the hood 12 to enable unobstructed visualization directly through one or more balloons 540. Additionally, the presence of multiple elongated balloons 540 rather than a single circumferential balloon may allow for one or more guidewires to exit hood 12 from multiple angles between adjacent balloons 540.

FIG. 51 shows a perspective view of yet another variation of the tissue visualization catheter. In this example, hood 12 may have an inflatable balloon 542 disposed within the open area of hood 12 where the distally exposed balloon surface

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defines a frictional surface **546** which allows for balloon **542** and hood **12** to be moved in a single direction when contacted against a tissue surface. The circumferential balloon **542** may also define an opening or lumen **544** therethrough to allow for the passage of instruments. The distal surface of the circumferential balloon **542** may comprise any biocompatible material having a higher coefficient of friction when urged in a first direction and a relatively lower coefficient of friction when urged in a second direction, e.g., a layer of fur, woven textiles, sheepskin, etc.

Accordingly, when balloon **542** is inflated beyond the distal end of hood **12**, the balloon surface in contact with the tissue may slide smoothly across the tissue surface in a first direction while being inhibited by relatively high frictional forces from sliding in a second direction over the tissue surface. Upon repeated inflation and deflation of balloon **542**, the visualization catheter may be pushed to move along a tissue wall in the direction where the coefficient of friction is low. This transverse motion of "walking" the catheter along a tissue surface may be utilized when an operator is attempting to locate a morphological feature along a body cavity, such as locating the coronary sinus along the tissue wall of the right atrium.

Turning now to FIG. **52A**, a variation of hood **12** having one or more curved or arcuate biasing suspension elements **550** positioned proximally about a circumferential contact portion **552** is illustrated for enhancing a seal between hood **12** and the underlying tissue surface. As shown, a number of biasing suspension elements **550** may be attached circumferentially in a first configuration about contact portion **552**, which may be an extension of hood **12** for contacting and overlapping upon the tissue surface. Biasing suspension elements **550** may be fabricated from a shape memory material, such as Nitinol, where the first configuration of the biasing elements **550** may urge contact portion **552** into a distally angled position relative to hood **12**. Moreover, as shown in the partial cross-sectional view of FIG. **52B**, contact portion **552** may comprise multiple projections **554** extending distally for contacting and adhering to the tissue surface. FIGS. **52C** and **52D** show detail perspective views of variations of the projections **554** including projections configured as extrusions or barbs **556**, as in FIG. **52C**, and flaps **558**, as in FIG. **52D**.

In use, when contact portion **552** is first placed into contact against the tissue T, as shown in FIG. **53A**, the distal portion of contact portion **552** and biasing elements **550** come into contact against the tissue T. Upon further axial loading **560**, hood **12** may be pressed towards the tissue T such that contact portion **552** and projections **554** become pressed against the tissue surface and the proximal portion of biasing elements **550** also come into contact against the tissue T such that the tissue underlying contact portion **552** is compressed between the proximal and distal ends of biasing elements **550**, as shown in FIG. **53B**. This configuration also increases the surface area hood **12** is in contact with against the tissue surface and hence improve sealing.

In yet another variation, FIG. **54A** illustrates a perspective view of a hood having a shape memory alloy, such as Nitinol, frame or scaffold **570** to enhance sealing between the hood and tissue surface, particularly uneven tissue surfaces. Scaffold **570** may include several contacting portions **572** extending along the hood and which are initially curved in an unbiased configuration, as shown in FIG. **54B**. When contacted against an uneven tissue surface, as shown in FIG. **54C**, the scaffold **570** may elastically deform such that the curvature of the hood conforms to the uneven surface upon further axial loading resulting in enhanced sealing with the tissue surface, as shown in FIG. **54D**.

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Yet another variation is illustrated in the perspective view of FIG. **55A**, which shows hood **12** having a circumferential contact portion **580** extending about the lip of hood **12**. Contact portion **580** in this variation may include a plurality of projections **582**, e.g., barbs or hooks, etc., which are angled inwardly towards a longitudinal axis of hood **12** such that when hood **12** and contact portion **580** are first placed into contact against the tissue surface T, as shown in FIG. **55B**, the contact portion **580** may spread over the tissue surface T, as indicated by the direction of movement **584** shown in FIG. **55C**, such that the projections **582** are engaged temporarily onto the tissue, thereby forming a seal between hood **12** and the tissue, as shown in FIG. **55D**.

To disengage hood **12** from the tissue, an axial force **560** may be urged upon hood **12** to first disengage projections **582** from the tissue, as shown in FIG. **56A**. This is followed by an infusion of additional fluid or gas **586** into the hood **12**, such as saline, such that the introduced fluid **586** flows between the projections **582** and the tissue surface to discourage re-engagement between the two, as shown in FIG. **56B**. Once projections **582** are fully disengaged from the tissue, hood **12** may be removed or relocated, as indicated by the direction of removal **588** in FIG. **56C**.

Yet another example is shown in FIG. **57A** illustrating hood **12** having a circumferential contact portion **590** which one or more electromagnetic rings or members **592** circumferentially positioned around the lip of hood **12**. A magnetic member **594** (e.g., ferrous magnets, rare earth magnets, Alnico magnets, ceramic magnets, etc.) positioned upon support **596** may be slidably introduced into hood **12** from catheter **16** such that magnetic member **594** is centrally positioned within hood **12**. During use, magnetic member **594** may be advanced distally into hood **12** in a proximate or adjacent position relative to the electromagnetic rings or members **592**, as shown in FIG. **57B**. Once contact portion **590** and magnetic member **594** have been placed into contact against the tissue surface T to be visualized, as shown in FIG. **57C**, magnetic member **594** and/or electromagnetic rings or members **592** may be activated to become electrically charged such that two are drawn magnetically towards one another. In so doing, the tissue between magnetic member **594** and electromagnetic rings or members **592** may be compressed or gripped such that a seal between hood **12** and the tissue T is enhanced, as shown in FIG. **57D**. Such a configuration may facilitate seal formation especially if the tissue surface is irregular, thereby making a contiguous seal between the tissue T and the lip of hood **12** difficult to achieve.

FIG. **58A** illustrates a partial cross-sectional view of a hood configuration having an outer membrane **600** and an inner membrane **602** which forms an annular space or channel **604** between the two and around the circumference of the hood. When transparent fluid **606** is injected through the annular channel **604**, a liquid seal or curtain may be created around the lip of the hood to improve sealing between the hood and tissue surface. Saline or other fluids may be injected through the walls of the hood and suctioned back into the hood and into the working channel. Fluid **606** injected this way from the hood wall is able to form a liquid seal or curtain between the outlet of the annular channel **604** and the tissue surface T, as shown in detail cross-sectional view of FIG. **58B**. This liquid seal or curtain may enable fluid **606** within the hood to be separated from the blood outside the hood and act as an additional seal to prevent leakage of saline. In addition, the liquid seal or curtain may also ensure sufficient sealing along uneven tissue surfaces.

Aside from various configurations and mechanisms for facilitating contact between the hood and the underlying tis-

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sue to be visualized and/or treated, additional mechanisms for clearing or purging the hood of blood may be implemented as well. For instance, FIG. 59A illustrates a perspective view of hood 12 where the infused transparent fluid may be injected into hood 12 in a spiral manner rather than injecting and flowing the fluid in a direction that is axial to hood 12. Although a single stream of fluid may be infused, this variation illustrates at least two spirally infused fluid streams 610, 612 injected from catheter 16. Infusion of fluid streams 610, 612 in a spiral manner may enable a more efficient and thorough flushing and displacement of the blood from hood 12 by systematically flushing the blood from the proximal end of hood 12 progressively out towards the distal opening of hood 12, as further illustrated respectively in the end and side views of FIGS. 59B and 59C. The spiral infusion of the fluid may also help to ensure that the infused transparent fluid more thoroughly covers every part of hood 12. Moreover, the centrifugal force imparted from the spiral flow 610, 612 may further provide additional structural support to hood 12. The presence of an instrument 614 advanced from catheter 16 into hood 12 may minimally impact and not interfere with the spiral flow 610, 612 in flushing hood 12.

Aside from varying the infusive fluid flow into hood 12, one or more cleaning brushes 622 (e.g., a soft brush or mop-like structure packed in a cylindrical configuration) may be optionally included within hood 12 for cleaning the lens or imager of debris which may accumulate or obstruct the imaging element in vivo during a procedure. In one example, FIG. 60B shows cleaning brush 622 incorporated into a proximal portion of hood 12 and distally of a visualization device, such as an optical fiberscope 620 positioned within catheter 16. Although a fiberscope 620 is shown in this example, other imaging systems may be utilized, e.g., CMOS, CCD, etc. As fiberscope 620 is passed distally through cleaning brush 622, any debris may be removed from fiberscope 620 such that an unobstructed image may be presented. Passing fiberscope 620 proximally and/or distally through cleaning brush 622 may be done prior to, during, or after each procedure to clear debris as needed or desired.

The applications of the disclosed invention discussed above are not limited to certain treatments or regions of the body, but may include any number of other treatments and areas of the body. Modification of the above-described methods and devices for carrying out the invention, and variations of aspects of the invention that are obvious to those of skill in the arts are intended to be within the scope of this disclosure. Moreover, various combinations of aspects between examples are also contemplated and are considered to be within the scope of this disclosure as well.

What is claimed is:

1. A tissue treatment system, comprising:

- a catheter having a flexible length and at least one lumen therethrough;
- a hood projecting distally from the catheter and having a first low-profile configuration and a second expanded configuration defining an open area therein, the hood including a contact portion extending circumferentially about a distal end of the hood, wherein the contact portion is configured to contact a tissue region to be visualized and fluidly isolate the open area; and
- a plurality of biasing suspension elements placed circumferentially around an external side of the contact portion, the plurality of biasing suspension elements each including a first portion attached to the contact portion and a second portion proximal of the first portion separated and curved away from the contact portion and a third portion proximal of the second portion attached to the

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contact portion such that the biasing suspension elements are configured to compress tissue between the first portion and the third portion.

2. The system of claim 1, wherein the plurality of biasing suspension elements comprise a shape memory material.

3. The system of claim 1, wherein the plurality of biasing suspension elements are distally aligned relative to the hood.

4. The system of claim 1, wherein the contact portion comprises a plurality of projections on an internal side of the contact portion, the projections configured to contact the tissue region.

5. The system of claim 4, wherein the projections comprise barbs.

6. The system of claim 5, wherein the barbs are angled inwardly towards a longitudinal axis of the hood.

7. The system of claim 4, wherein the projections comprise flaps.

8. The system of claim 1, wherein the deployment catheter is steered via at least one push-pull wire.

9. The system of claim 1, wherein the hood is comprised of a compliant material.

10. The system of claim 1, wherein the biasing suspension elements are configured to compress tissue between the first portion and the third portion upon axial loading on the catheter.

11. A catheter comprising:

at least one lumen therethrough;

a hood projecting distally from the catheter and having a first low-profile configuration and a second expanded configuration defining an open area therein;

a pliable contact portion extending circumferentially about a distal end of the hood to fluidly isolate the open area against a tissue region; and

a plurality of projections positioned circumferentially around and extending from an internal side of the pliable contact portion;

a plurality of biasing suspension elements placed circumferentially around an external side of the contact portion, each biasing suspension element including a first portion attached to the contact portion and a second portion proximal of the first portion separated and curved away from the contact portion and a third portion proximal of the second portion attached to the contact portion such that the biasing suspension elements are configured to compress tissue between the first portion and the third portion.

12. The catheter of claim 11, wherein the plurality of biasing suspension elements comprise a shape memory material.

13. The catheter of claim 11, wherein the plurality of biasing suspension elements are distally angled relative to the hood.

14. The catheter of claim 11, wherein the projections comprise barbs.

15. The catheter of claim 14, wherein the barbs are angled inwardly towards a longitudinal axis of the hood.

16. The catheter of claim 11, wherein the projections comprise flaps.

17. The catheter of claim 11, wherein the hood is comprised of a compliant material.

18. A catheter comprising:

at least one lumen therethrough;

a hood projecting distally from the catheter and having a first low-profile configuration and a second expanded configuration defining an open area therein;

a pliable contact portion extending circumferentially about a distal end of the hood, the contact portion configured to fluidly isolate the open area against a tissue region; and

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a plurality of biasing suspension elements placed circumferentially around an external side of the contact portion, the plurality of biasing suspension elements each including a first portion attached to the contact portion and a second portion proximal of the first portion separated and curved away from the contact portion and a third portion proximal of the second portion attached to the contact portion such that the biasing suspension elements are configured to compress tissue between the first portion and the third portion; and

a plurality of projections positioned circumferentially around and extending from an internal side of the pliable contact portion.

**19.** The catheter of claim **18**, wherein the plurality of biasing suspension elements are distally angled relative to the hood.

**20.** The catheter of claim **18**, wherein the plurality of projections comprise barbs that are angled inwardly towards a longitudinal axis of the hood.

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